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DISPLAYING UNCERTAINTY: A COMPARISON BETWEEN SUBMARINE SUBJECT MATTER EXPERTS

by

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March 2007

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This experiment presents four individual scenarios to three submarine TMA experts: Commanding/Executive Officers (CO/XO), Department Heads (DH), and Fire Control Technicians (FT). Ten individuals from each expert group volunteered from the Groton, CT, and Bangor, WA, submarine bases.

A between subject design experiment compared the ranges, range envelopes, time, and over or under estimations of range to the contact generated by each group of experts. After the experiment subjective and objective data were analyzed in order to determine what, if any, differences exist between the three different experts.

The results indicate that there was no significant difference between experts. Recommendations address improvements in experiment implementation which can be integrated into future studies as well as the design of improved decision aids.

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DISPLAYING UNCERTAINTY: A COMPARISON BETWEEN SUBMARINE SUBJECT MATTER EXPERTS

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EXECUTIVE SUMMARY

Submarines cannot see underwater so the crew is forced to make decisions based on information provided by the submarine’s sensors. Passive sensors provide information that is uncertain, and uncertainties in the information displayed on a submariner’s computer screens ultimately affect the decisions made by the Commanding Officer.

Areas of uncertainty (AOU) refer to a graphical display tool that has been developed in order to place more confidence in the uncertain data obtained by passive sensors. A decision aid that can best represent AOUs to a variety of users is a much sought after tool. A more effective decision aid can be developed by evaluating the differences between different submarine subject matter experts (SMEs).

This thesis evaluates the differences in TMA performance between the Commanding/Executive Officers, Department Heads, and Fire Control Technicians with regard to how they construe uncertain information when displayed in the AOU format. No significant difference was noted between the three expert groups regarding range accuracy. The results of this study have been forwarded to the Naval Undersea Warfare Center (NUWC) in order to develop AOU decision aids to be used by the fleet.

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1. INTRODUCTION

Submarines are becoming a useful tool in establishing safer ocean boarders and accomplishing strategic objectives. Many aspects of the submarine service have changed over the past 107 years. Advancements in technology have altered the way submariners conduct their business. Many nations are either producing or purchasing more submarines in order to reap the benefits of these “denizens of the deep.”

A. TARGET MOTION ANALYSIS RESPONSIBILITIES

Ultimately the responsibility of the submarine rests upon the shoulders of the Commanding Officer (CO). When a submarine is engaged with a threat, either surfaced or submerged, the CO will typically rely upon a team of individuals comprised of the Executive Officer (XO), Department Heads (DH), and Fire Control Technicians (FT) in order to maneuver the boat without incident. While a submarine is submerged it is blind with the exception of information received by the Sound Navigation and Ranging (sonar) equipment. As technology has advanced so have the means by which we can interpret sonar data. Even highly sophisticated equipment provides data that contains some degree of uncertainty. Data uncertainty is generated by many sources in the environment and the submarine itself. Making decisions, given the data uncertainty, is a challenging task for any seasoned submarine crew.

When a contact of interest (COI) is initially detected, a section tracking party will be stationed in order to track the contact in a more detailed manner than

what is normally assigned. Submarine crews routinely conduct just enough Target Motion Analysis (TMA) on a contact in the open ocean environment to safely navigate the ship without collision. The stakes are higher when submerged in a high density surface environment (lots of contacts) or when detecting another submerged submarine; more individuals are required in the control room in order to safely navigate the ship.

B. SOUND NAVIGATION AND RANGING CHARACTERISTICS

Sonar systems listen to sounds in the surrounding environment and report any noise detections to an operator. The sonar operator will then interpret the reported noise in order to classify the source. The source of the sound could be anything from biologics (fish) to an anchor chain used on a buoy that marks a traffic lane in a strait. No matter where the sound originated from it is priority number one to determine if the sound source is a threat to the safety of the submarine.

A submerged submarine presents a unique environment for sonar operators solving range estimates to other submerged contacts. When provided with two parameters (bearing and frequency), sonar operators are challenged to generate three new parameters (course, speed, and range). These parameters are used to classify the contact and provide solutions to targets.

Data provided by sonar systems are distributed to equipment that is used by the CO, XO, DHs, and enlisted specialists such as FTs. Each of these individuals approach a submerged contact scenario based on their own intuitive skills that they have been taught or learned by

experience throughout their careers. These three groups have a different level of achieved skill and when working together provide an excellent combined team effort in order to successfully accomplish the many difficult tasks of submarine life.

C. AREA OF UNCERTAINTY

Sound travels differently in water than it does in air. Water provides a difficult challenge for sonar operators when trying to locate the source of sound. Background noise in the ocean environment, depth of the water, and even the composition of the water provide an added degree of uncertainty with regard to the source location. The equipment used by submarine operators and decision makers is a lot better than that used in the past; however, there will always be some degree of uncertainty with regard to the information that is provided to the operator.

During an encounter with another submerged contact a submarine crew must adequately deal with the uncertainty in the data in order to safely conduct their operations. An Area of Uncertainty (AOU) is generated so that the submariners can have an idea of the whereabouts and direction of motion of the submerged contact. AOUs provide a general understanding of the contact while the crew is working to determin the exact location of the source. As more time elapses and a better understanding of the contact develops, the AOU will shrink in size and provide more benefit to those trying to analyze the contact.

D. ILLUSTRATIVE EXAMPLE OF AN AREA OF UNCERTAINTY

Imagine that you want to take your family to the zoo in order to see the new lion exhibit. After parking the car and walking to the zoo entrance you hear a lion roar. Without using any maps of the zoo it would be hard to pinpoint the exact direction from which the noise originated. It would be safe to assume that the noise came from inside the zoo so the AOU would be the area of the whole zoo.

After entering the zoo the lion roars again. This time it is louder and more directional. If you were to hear the noise from your left side then it would be safe to say that the lion is not on your right. A louder roar also indicates that the exhibit is much closer than it was originally. The generated AOU for the lion has changed in size to a smaller area because the direction to the noise is more discernable than it was in the parking lot.

After walking to your left for a few minutes, and without using a map to the exhibit, the lion lets out another roar. This time the noise is much louder and even more directional. The AOU for the lion’s exhibit becomes even smaller than it was when you initially entered the zoo and we can pinpoint almost the exact location from which the noise came. A skilled person who has heard many roars from lions before may even be able to estimate the correct distance to the exhibit.

In the above scenario, some sources of uncertainty may make it more difficult to determine the best course to get to the lion exhibit. Factors such as fog in the parking lot, construction in the zoo, or even human limitations

like hearing loss would add to the confusion of trying to locate the exhibit. The fog would hide the size of the zoo so the initial AOU would have been much larger. Any construction in the zoo may mask the lion's roar and make it difficult to pinpoint the source. Human hearing loss would also add to the confusion of where exactly the roar originated and all of this uncertainty would have produced larger AOU sizes during the scenario progression.

E. APPLICATION OF THE AREA OF UNCERTAINTY

During a section tracking party evolution there are more people in the submarine control room than during normal business hours. This increase of submariners permits a more effective analysis of a contact by allowing more skilled operators to analyze the sonar data. The initial detection of a contact usually is the cause for stationing the section tracking party. Detecting a submerged contact from longer distances allows more time to station the section tracking party, who can therefore begin the analysis before the contact becomes too close.

Bearing and frequency are the key components received by the sonar equipment. By using these two valuable bits of information, contact solutions can be computed to gain a better understanding of how the contact is behaving. As time progresses and information is received and analyzed, a better understanding of what the contact is doing will develop.

Several independent stations onboard the submarines work to analyze contact data. A geographical plot is used to generate several different AOUs during the encounter. Initially the AOU will be large because of the increased

amount of uncertainty with regard to the sonar contact. As the scenario progresses, and confidence in the signal either increases or decreases, the AOU will change inversely. The AOU is not the sole source of a contact’s evaluation but it does provide a lot of insight and also provides a historical view of what the contact did during the encounter.

As several AOUs develop over a period of time, an understanding of the contact’s motion is established. For example, if you stood outside the lion exhibit and closed your eyes, you could listen to the roars of the lion very clearly. If initially you hear the lion roar to your left and subsequently hear the lion roar to your right, you could deduce that the lion is traveling from left to right.

A contact solution is generated by the geographical plotter based on observing the generated AOU and is provided to the XO. Several different sources of contact, such as the time frequency station and the sonar supervisor, evaluate the contact’s information in order to generate their own independent solutions. The XO is required to obtain as many differently sourced contact solutions as possible in order to determine the best possible solution for the contact. The solution provided by the geographical plotter based on AOU will be assigned a certain level of confidence by the plot supervisor and the XO will take this confidence into account while generating his own solution. The combined solution generated by the XO is then passed to the CO as the best possible solution. The CO will add another level of scrutiny and will base his command decision on this refined contact solution. The

whole process is extremely challenging and requires skilled operators in order to effectively conduct target motion analysis (TMA) operations.

F. PROBLEM DEFINITIONS

There are many steps involved in producing a solution that has a high confidence level to the CO. The AOU is a small but important part of the process. Making decisions given uncertain information is a daily event onboard a submarine. More accurate range estimates can be determined if an AOU is utilized by submariners during the TMA process. During a submerged contact scenario, observing the AOU changes over a given time period will allow the operator to accurately estimate the contact’s range and to estimate an accurate solution to the COI.

It is unknown how accurate submarine operators are at estimating ranges given the AOU data. There are generally three different recognized expert analysts onboard U.S. submarines that use the AOU. To make an assumption that they analyze the AOU differently is logical. It is also logical to assume that all three groups (CO/XO, DH, and FTOW) would have different accuracies once they generate a range estimate based on the AOU. A better understanding of the differences between these three groups of individuals allows for further research into how to possibly display an AOU best and the users can then report better TMA range estimates when they are presented with uncertain data.

G. METHODOLOGY

The research was conducted by presenting the three different groups of submarine TMA experts with several

scenarios involving AOUs. During each computer generated scenario the AOUs shifted around the monitor to simulate contact motion. Basing their contact solution on the displayed AOU, each participant's solutions were scrutinized.

The range estimates were examined through extensive statistical analysis in order to determine if there was indeed a difference in accuracy between the three groups of experts. Any significant differences in accuracy will provide for further research investigations. The difference between the participant's solution and the scenario truth was used as the measure of effectiveness (MOE). A smaller range difference indicates that the participant was more accurate than if they had generated a large range difference.

II. LITERATURE REVIEW

A. TARGET MOTION ANALYSIS

Target motion analysis (TMA) is used by submarine operators to locate and track contacts in submerged environments. The process of TMA is time consuming; several refined solutions for a given contact are required before a section tracking party obtains an accurate solution. This chapter provides background information on the types of sonar that are available, the TMA process, and the different causes of uncertainty when obtaining data during a TMA evolution.

A submerged submarine presents a unique environment for sonar operators solving for range estimates to other submerged contacts. When provided with two parameters (bearing and frequency), sonar operators are tasked with the difficult job of accurately producing three parameters (course, speed, and range). Research has demonstrated that sonar operators can provide more accurate range estimates to a submerged contact if they are given a graphical representation of the uncertainty surrounding their sonar solutions (Kirschenbaum and Arruda, 1994; Brolese, 2005; Brolese and Huf, 2006).

1. Sound Navigation and Ranging

There are two basic types of sonar: active and passive (L-3 Communications SeaBeam Instruments, 2000; Liberty, 2006). Most submarines can use an active sonar system that transmits a pulse of sound energy into the ocean and listens for a returned echo. A returned echo may help a submarine’s fire control tracking team locate a Contact of

Interest (COI). Active sonar typically provides a more accurate solution for the contact; the drawback to using active sonar is that the submarine will give away it's position to a contact.

More often than not, submarine crews will track their prey using passive means (Liberty, 2006; Dry, Lee, Vickers, and Huf, 2005). This is done by using different sensors (or arrays) in order to passively obtain contact information while emitting a minimal amount of noise into the environment. Using passive sonar allows submarines to remain quiet and still formulate a solution to a contact they are tracking. The submarine tracking party can only calculate a solution based on the information that is received by the sensors. While tracking a contact with passive sonar a submarine crew is limited to whatever noise the contact emits. Bearings (By) and frequency (f) are the two main parameters detected with passive sonar and are both utilized when calculating solutions to a COI (Coll, 1994; Bakos, 1995).

2. Signal Frequency

Frequency of the received signal can be used to identify the source of the signal, estimate a range to the contact, and eventually generate an independent contact solution. All submarines generate a unique noise signature that is susceptible to detection by a submerged sensor (Liberty, 2006). This unique signature allows the crew to classify the submarine. Before a submarine crew deploys they gather intelligence on suspected submerged contacts they may detect while on deployment. Using this intelligence, an estimate of the COI's maximum speed and

behavioral patterns can be postulated by the watch section. Speed data is a key factor in determining the contact’s solution as the scenario progresses.

A range estimate to the COI can be calculated by evaluating several parameters regarding the local marine environment, then using these parameters to predict the distance that noise could travel and be detected. Equipment used by the section tracking party is limited by the sensitivity of the sensors in the passive sonar arrays. By understanding the limitation of the passive sonar sensors a prediction can be made regarding the effective range at which any contact can be detected. Frequency data obtained on the COI may also be used to determine the maximum range of a contact. High frequencies typically indicate the contact is closer. Some low frequencies can travel extremely long distances certain water temperatures. Higher frequencies suffer too much attenuation, over long distances.

3. Bearing

Bearing data on a contact is obtained from the ship’s sensors. By observing contact bearings, for a given time period, a bearing rate can be calculated. For example, if an initial detection on a submerged contact has a bearing of 090 and ten minutes later the contact has a bearing of 080, then the calculated bearing rate is: left one degree per minute. Bearing rates are continually being updated and are a necessity in order to best understand what the COI is doing. A high bearing rate (five degrees per minute) typically indicates the contact is close; a lower bearing rate (one degree per minute) is an indication that

the contact is further away. However, these are general rules of thumb as there are always exceptions regarding range estimates based on bearing rates.

Figure 1 shows an example of bearing data from a submerged contact. When a submarine crew plots bearing data to a contact, initially there is a large number of possible solutions for the COI. Two of these possible solutions for the contact are depicted by S1 and S2 respectively. Both S1 and S2 require the COI to travel at different speeds and ranges. A submarine tracking party will use a variety of tools and equipment to analyze the data to calculate the best contact solution. The amount of data obtained on a given contact can be overwhelming.

This thesis is part of an ongoing experiment by the Naval Undersea Warfare Center (NUWC) in order to better understand how experts view AOUs. The rationale for this thesis experiment is to reduce the cognitive load on the fire control tracking team by examining possible displays and identify differences in performance based on experience. Cunningham and Thomas (2005) provide an excellent source for more in depth TMA background information.

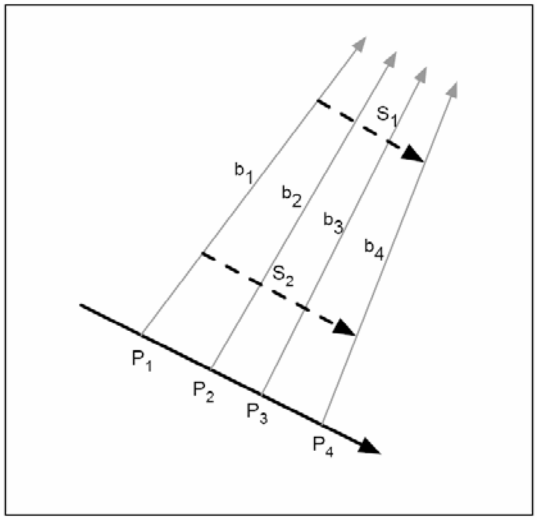

Figure 1. Example of Bearing Data.

Figure 1 is a display of a simplified scenario illustrating the nature of TMA bearings. For this example, ownship is taking a path defined by the points P1..4 and is assumed to have a constant velocity and have regular bearings sample rate. Each point is equidistance and represents the point at which the bearings B1..4 were taken. These bearings give an indication of the direction of the target relative to the point of ownship where the bearings were taken. (From: Cunningham and Thomas, p. 82, 2005).

4. Uncertainty

Unlike the surface Navy where sailors can use visual means to locate contacts, submariners rely upon their equipment to detect contacts. This reliance upon sonar imposes restrictions upon the degree of confidence that is placed upon the received data (Dry, et al, 2005; Schunn, Kirschenbaum, and Trafton, in press; Brolese and Huf, 2006). The ocean environment, submarine equipment, and even the submariners themselves generate a large amount of uncertainty in this inherently difficult task. Considering the sources of uncertainty permits a section tracking party to generate contact solutions in which the assumptions and potential flaws or weaknesses are made explicit.

Sound travels approximately five times faster in water than it does in air because water is much denser. Sound is also more susceptible to interference in water because the characteristics of the fluid can change rather quickly in an ocean environment. The density of the water is affected by pressure, temperature, and salinity (Liberty, 2006). Signal ambiguity develops because sound does not typically travel in straight lines (Kirschenbaum and Arruda, 1994).

Temperature and salinity can change rather quickly because of ocean currents and environmental factors. These factors are not typically predictable. Pressure changes are the most predictable because it changes only with depth. The varying density of water will affect the speed and path in which sound travels through water. (Schmidt, Chayes, Caress, 2006). This new, unpredictable path the sound traveled through the water increases the level of uncertainty with regard to any contact solution that is generated.

The submarine sensors and electronic gear used in passive sonar systems are not perfect. After a signal is detected by the sonar system it is processed by electronic equipment and presented to an operator. A small degree of uncertainty is generated between the sensors detecting a signal and the signal being presented to an operator because of the algorithms used by the computer (Kirschenbaum and Arruda, 1994). The human operator, similar to the sensor, has inherent flaws in judgment and sensory skills required for analysis. Even when uncertainty is high decisions must be made. Any tool that

could assist a section tracking party in making better decisions, given these uncertain conditions, would be worth investigating.

5. Area of Uncertainty

An AOU can be calculated using computer algorithms based on environmental parameters and contact information. Figure 2 illustrates an example of a possible AOU with two different colored ellipses generated for the contact in Figure 1. The inner ellipse indicates a probability that is less than the probability represented by the inner and outer ellipses combined. For example, the inner ellipse could represent a 66% probability that the COI is located within that region and the outer ellipse could indicate a 95% probability the COI is located within both the inner and outer ellipses combined. Research is ongoing to determine the best combination of ellipse probabilities in order to best represent uncertainty.

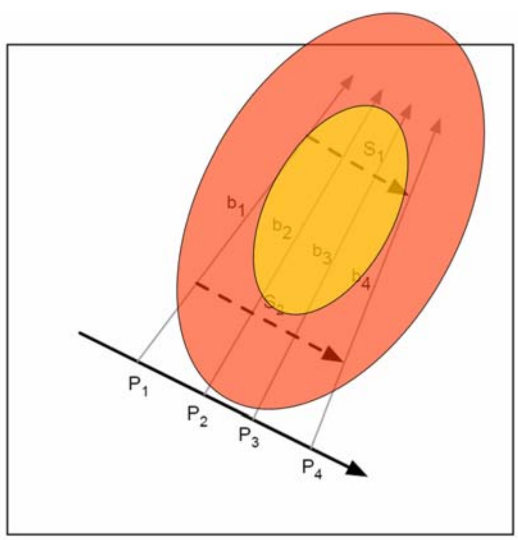

Figure 2. Possible AOU for the Bearing Data in Figure 1.

During each ownship maneuver phase of the contact evaluation, the AOU will change based on subsequent data received. As more data is obtained on the contact, unlikely solutions can be eliminated, and the AOU will shrink in size. With a smaller AOU, the process of predicting a contact solution becomes more reliable. If the mission is to launch a torpedo or to go to periscope depth the AOU can provide a good estimate for range data on the contact during that evolution.

6. Area of Uncertainty Research

When a graphical representation of uncertainty is displayed for users, the degree of effectiveness of the displayed uncertainty varies with regard to the difficulty level (easy or hard) of the scenario. Large differences in the performance of participants between easy tasks (low noise scenarios) and harder tasks (high noise scenarios) have been observed (Kirschenbaum and Arruda, 1994; Brolese, 2005). When comparing the use of uncertainty ellipses it was demonstrated that the aid was only effective during the harder scenarios.

Kirschenbaum and Arruda investigated the effects of using a graphical representation of uncertainty to represent the probability that a contact is contained within the ellipse (Kirschenbaum and Arruda, 1994). Brolese extended the Kirschenbaum and Arruda research to investigate what method of uncertainty representation leads to the best overall performance by the operator (Brolese, 2005).

There were two different scenarios presented to the participants in the Brolese study. Five different ellipse

probabilities were used in both scenarios. Brolese measured the percentage of times a participant was able to correctly estimate a range to a contact for all ellipse percentages. Specifically, the contact had to be contained within the range limits set by the participant. The range estimates reported by the participants using the 95% ellipse contained the COI approximately 60% of the time. The research demonstrated that the 95% ellipse was more effective in supporting participants when estimating overall range data to contacts.

Figure 3 supports that in difficult scenarios, unlike easier scenarios, there was indeed a significant difference in the accuracy of range estimates provided by the participants. In the more difficult scenarios both the 50% and 95% AOU produced approximately similar results with regard to minimizing absolute range errors. The 95% ellipses had the most pronounced effect on aiding the participants’ performance during both the difficult tasks and easier tasks in that it produced the lowest absolute range errors and more correct range estimates on average.

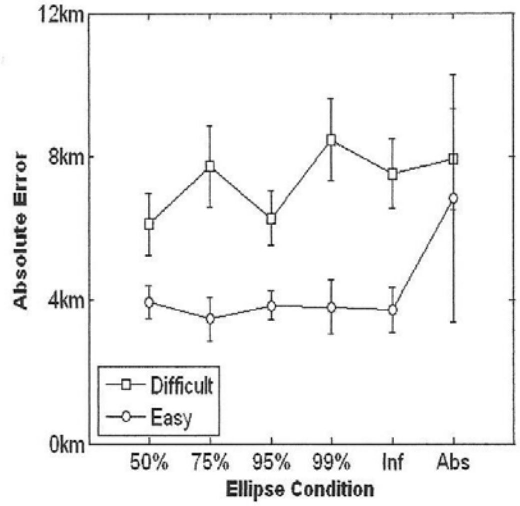

Figure 3. Ellipse Condition versus Absolute Error. (From: Brolese, 2005).

7. This Study

The primary aim of the present study was to continue to explore the findings of Kirschenbaum and Arruda (1994), and Brolese and Huf (2006), by examining the effect of expertise of users regarding displayed uncertainty. Kirschenbaum and Arruda recommend further research in the perceptual and cognitive elements used by submarine experts and their use of uncertainty ellipses to better understand the role of expertise in range estimations (Kirschenbaum and Arruda, 1994).

The AOU provided to participants in the present study was similar to the 95% ellipses shown in previous studies. During the course of the present study, Brolese and Huf reported additional research that casts doubt upon which ellipse AOU (50% or 95%) provides the most benefit to the user (Brolese and Huf, 2006). These findings may be of military significance to the Australian Navy because their

submarine operators are only provided a 95% ellipse. Brolese and Huf demonstrated that “50% ellipses consistently lead to more correct and accurate proximity decisions than the currently utilized 95% ellipse” (Brolese and Huf, 2006, p. 5).

Given the conflicting findings between the two studies it was decided that the use of an ellipse to depict a 95% AOU would not be inappropriate for the present study. All participants were subject to the same conditions during the experiment and the purpose of the study was to determine any significant differences in performance between the different groups of subjects.

By administering scenarios to operators with three different levels of expertise within the submarine community, the mission is to determine if there are any significant differences in range estimates between subjects. The different levels of expertise are: commanding/ executive officers, department heads, and fire control technicians. All three groups of experts responded to the same scenarios and their contact solutions were analyzed to determine if one particular expert group provided more accurate ranges.

B. DECISION AIDS

The ability of submariners to interpret and reason with decision aids is increasingly important as technology advances. Some of the cognitive workload may be mitigated by the use of well-designed decision aids. An aid that reduces mental workload and allows a user to obtain needed information “at a glance” is a much sought after tool (Hutchins, 1996; Larkin and Simon, 1987). Cognitive

scientists and cognitive systems engineers are among those who are skilled at understanding the way in which humans interact with their environment.

Diagrammatic representation and reasoning is an area of research that is focused on how humans or machines can represent information using diagrams and solve a problem or answer a question while using those diagrams (Narayanan, 1997). Cognitive scientists apply diagrammatic reasoning to understand the interaction of three complex factors: cognitive and perceptual skills of the user, graphical properties of the external representation, and the requirements of the specific task being undertaken (Peebles and Cheng, 2003).

Regarding depicting AOUs, a number of investigations have reported how cognitive and perceptual skills of the user, graphical properties of the external representation, and the requirements of the specific task being undertaken have affected the user (Kirschenbaum and Arruda 1994; Brolese 2005; Brolese and Huf 2006). The focus of these investigations was to develop a tool specifically designed to represent uncertainty with the goal of supporting submariners in their decision making process.

Submariners operate in an extremely complex environment. The size of the crew is limited so there are typically several tasks assigned to each member of a watch section. Multitasking is an advantage only when the user can efficiently perform each task. As the number of tasks increase so does the amount of information that needs to be assessed. Designers of graphical interfaces seek to consider how different quantities are encoded and how to

balance the cost of familiar representations with computationally advanced representations in order to enable a user to efficiently analyze the data. Guidelines for further development of visual displays and graphical interfaces have been developed by research (Peebles and Cheng, 2003).

1. Principles of Decision Aiding

Decision theorists argue that in order for optimal decision making to take place a thorough analysis of all data and hypotheses must occur; these evaluations typically involve complex equations and extensive calculations in order to arrive at an optimal decision. Analysis strategies employed by decision makers generally involve sophisticated mental computations and a lot of data (Hutchins 1996, Dry, Lee, Vickers, and Huf, 2005).

Graphics, by virtue of the presentation of an integrated, synthesized representation of the critical data, allow users to omit time consuming steps, such as calculations and estimations, in their evaluation of data. For example, during a contact evaluation in a submarine scenario, several range estimates to a COI are calculated. These calculations are typically cognitively challenging, as well as time consuming. When a graphical depiction of range is available this eliminates the need to calculate range and thus frees up an operator’s mental capacity for other tasks (Hutchins 1996; Dry, et al, 2005).

Beyond range calculations, a large amount of data (speed, course, bearing, range, and bearing ambiguity when using a towed array) need to be analyzed by a submariner during the TMA process. In addition to the processing of

data, working memory is required for other tasks. An Officer of the Deck (OOD) uses working memory to maintain a list of actions taken by the section tracking party during an evolution and for predicting possible scenario outcomes.

Predicting is a difficult cognitive task that depends heavily on working memory (Wickens, Lee, and Liu, 2004). In order to predict accurately one must consider current conditions, future conditions, and then mentally simulate, using the decision maker's mental model to determine the expected outcome. When our mental resources are tasked to the limit (maximum capacity) or overrun with several concurrent tasks our ability to predict rapidly deteriorates. A graphical display that includes a summary of critical data would decrease the cognitive workload required to synthesize the data and free up the mental capacity of the OOD for other tasks.

In the process of reducing the mental workload required of a submariner, well designed displays may also produce the additional benefit of minimizing the amount of human error in decision making. The operation of these systems in the fleet is the true test of how well the principles of decision aiding have been observed during the research and development phase of production.

Newly developed systems will be judged on their ability to minimize the amount of incompatibility placed between the system and the user (Hutchins, 1996). Research on the way humans perceive displayed information and make decisions on that information is important in developing decision aids that minimize mental workload, provide needed information "at a glance", and minimize human error.

2. Data Fusion

The quality of an aid and the way the human utilizes the information provided by the aid are two factors that ultimately determine the user's performance during a task. Specifically how much trust the user places in the aid, the way in which information is presented to the user, time pressure, and the level of risk involved affect the overall utilization of an aid. The process of data fusion involves input from several sources, each of which provides information at a different level of abstraction (Bisantz, Finger, Seong, and Llinas, 1999).

Information provided from a data fused plot is presented to the user through the computer interface. These interfaces require training the user before the user can fully understand what is presented. An interface with multiple levels of information presented in a fashion that is easily understood by the user can save time and effort when formulating solutions in a complex, uncertain environment. Specifically, ease of recognition is directly related to how explicit and implicit information is represented (Larkin and Simon, 1987).

3. Factors Regarding an Aid (Trust and Presentation)

a. Trust

Trust in an advanced automated system does not come easily. The amount of trust placed in an aid will affect a user's reliance on the system (Sheridan, 1988). Empirical results suggest that the strategy employed by users may be affected by the trust in that system. For example, when participants required financial advice from

an automated system, confidence in the system declined when poor advice was given (Lerch and Prietula, 1989). A new strategy for most users was to not use the system at all because of the lost trust.

b. Presentation

The utility of an aid is determined by how the information is presented. Past research has focused on how to display uncertainty so that the true probabilities of the data can be presented to a user (Kirschenbaum and Arruda, 1994; Andre and Cutler, 1998; Brolese and Huf, 2006; Brolese, 2005). The research by Andre and Cutler (1998) and by Kirschenbaum and Arruda (1994) demonstrate that different visual representations of uncertainty resulted in a measurable difference in user accuracy. Brolese and Huf (2006) and Brolese (2005) built on the Kirschenbaum and Arruda (1994) research by determining how to specifically represent uncertainty visually in order for the user to achieve the most accurate result.

In the research by Andre and Cutler, when no visual representation was provided to the user, the participants appeared to forget that there was any degree of uncertainty involved in the experiment. Kirschenbaum and Arruda (1994) demonstrated that when verbal representations of uncertainty were presented to their participant performance was less accurate than when an elliptical ring representing uncertainty was displayed. These findings suggest that it is worthwhile to continue investigating how best to visually represent uncertain information.

A well-designed decision aid will support the user by reducing the demand on the limited cognitive processing capability of human beings (Dry, et al., 2005). Because of our limited processing abilities, a decision maker may fail to remember critical data, overlook important information, make decisions too hastily, and possibly make decisions that are not correct (Hutchins, 1996).

4. Graphical Displays

Graphical displays visually present measured quantities of data by providing combined points, lines, a coordinate system, numbers, symbols, words, shading, and color to a user. Graphics are instruments that support complex reasoning about the quantitative information provided. Well-designed data graphics are typically the simplest, and at the same time, the most powerful form of information presentation available (Tufte, 2001).

Graphical displays should show data in a format that best supports the user’s needs, induce the viewer to think about the substance of what they are viewing rather than the means of getting it, avoid distorting what the data represent, encourage the eye to compare different pieces of data, and be closely integrated with the statistical descriptions of a data set (Tufte, 2001). The more closely the presented data represent the needed information to the user, the better the user can effectively use the data. Larkin and Simon (1987) believe the advantage of a good diagram is computational; that is, the representation of

information is not necessarily based on the amount but on the ability of the user to successfully compute accurate results.

There is limited research on the impact of displayed uncertainty on the performance of decision makers (Brolese and Huf, 2006; Kirschenbaum and Arruda, 1994). Research on how graphical displays can represent data the most effectively is imperative for a technologically advanced society.

5. Advantages of Graphic Displays

Recent technological advancements have led to dramatic increases in computational speed and sophistication of the graphical display capabilities of computers. New technological formats will interact with task structure and improve situational awareness and task performance of submariners (Kirschenbaum and Arruda, 1994). Research in required to determine how these new improvements will affect a user’s ability to analyze data and make decisions.

While the processing capabilities of computers have increased the processing capabilities of the user have not. If display designers do not take into account the limitations of the user, then it is unlikely that the true potential of the new technology will be realized (Dry, et al., 2005). Technological improvements with respect to automation do not necessarily translate into benefits for the user (Roth, Patterson, and Mumaw, 2002).

Representation aiding is where direct manipulations and graphical techniques make abstract information more concrete in complex and dynamic domains (Bennett, Toms, and

Woods, 1993). Analog to digital conversions are required in order for data to be presented in these new formats. Configurable properties of the data displayed can be either structural or dynamic. The structural and dynamic properties of a display describe the behavior or movement of graphical elements with respect to other elements (Bennett, Toms, and Woods, 1993).

6. Cognitive Engineering

"Cognitive engineering is an interdisciplinary approach to the development of principles, methods, tools, and techniques to guide the design of computerized systems intended to support human performance" (Roth, Patterson, and Mumaw, 2002, p. 164; Roth and Woods, 1988). The main cognitive areas of concern are problem solving, judgment, decision making, attention, perception, and memory. The goal of cognitive engineering is to develop interactive systems that are easy to learn, and easy to use, with the end result being improved user performance (Roth, Patterson, and Mumaw, 2002).

Cognitive engineering advocates that users and the tasks they perform should be the central focus for system design specification. The design of systems is viewed as a means to create a tool that assists users in their decision making. This approach benefits the user because the computer-based tools and aids will be designed to solve the appropriate problem. Cognitive engineering provides opportunities for computational technology to increase the potential to facilitate and augment human cognitive activities, e.g., advanced data visualization techniques used in decision making (Roth, Patterson, and Mumaw, 2002).

Considerable time and money have been spent developing cognitive tools to improve human interfaces with technologically advanced software. A specific tool was designed to support cognitive engineers in developing software which models and documents the Cognitive Task Analysis (CTA). The Computer-Aided Cognitive Systems Engineering (CACSE) tool's benefit is that the design of a Decision Support System (DSS) will be a direct result of the cognitive issues and relationships determined during the CTA. "System developers using the CACSE-supported process would deliver fully functional DSSs that embody solutions to the cognitive demands of the domain and provide dramatically improved joint (human + DSS) decision-making effectives – a critical component of information dominance" (Potter, Elm, Roth, and Woods, 2001, p. 2).

7. Psychological Implications for Submarine Display Design

a. Perceptual Factors Influencing Display Design

Perceptual factors must be considered by engineers in the designing of displays. Several factors may make it difficult for a user to effectively use a display to make decisions. When using grey scales for displayed information, the background may determine the brightness of the different shades used. These varying levels of contrast may be distracting to the user and may also cause additional mental fatigue.

When using color in display design, there are implications as to which colors are located adjacent to each other (Dry, et al, 2005). For example, red and blue

should not be used in close proximity because of a phenomenon called chromatic aberration. Chromatic aberration is the difference in wavelengths between two colors in close proximity where the user cannot focus on the two colors at the same time (Bradley, Zhang, and Thibos, 1989).

b. Cognitive Factors Influencing Display Design

Designing displays requires that human cognition be evaluated in order to increase the usefulness of the display (Wickens, Lee, and Liu, 2004). Several factors such as attention and short-term memory limitations require consideration when designing displays. Humans can only pay attention to limited amounts of information for limited amounts of time (Wickens, Lee, and Liu, 2004; Dry, et al, 2005).

The short-term memory limitations of the display's user must also be considered. Too much information on a display will limit the users effectiveness with regard to the decisions that are made based on the information presented. The amount of information that can be stored in short-term memory is believed to be five to nine items, varying according to complexity, presentation sequence, and length of time the information must be remembered (Dry, et al, 2005).

8. Quantity of Information Presented in an Aid

Research provides an understanding of the quantity of information required by experts while making decisions. It has been suggested that it is not necessarily the quantity of information used by experts, but the ability of the

expert to focus on what information is relevant (Ettenson, Shanteau, and Krogsad, 1987; Shanteau, 1992b). Researchers and decision aid developers must take into account the cognitive factors of the human when designing their work. Quality, not the quantity, of information should be emphasized by designers who are building aids for decision makers.

C. EXPERTISE AND DECISION MAKING

Judgment and decision-making (J/DM) is an important topic of study for human factors researchers. Two specific fields to study within the topic of J/DM are experts and expert systems (Shanteau and Stewart, 1992). In the fields of decision making, planning, and problem solving, expertise has been one of the most difficult concepts to understand, capture, and quantify (Serfaty, MacMillan, Entin, and Entin, 1997). Even though experts are perceived by non-experts as “those people with all the answers” and are the ones we trust in their specific field they are certainty not perfect. In fact, experts have cognitive limits, individual characteristics, and preferred strategies that are common amongst their everyday practices (Shanteau, 1988; Wickens, Lee, Liu, and Becker, 2004). Experts certainly are not infallible and their complex behaviors are just one reason they are so difficult to study (Edwards, 1992).

Many experts employ decision aids. It would be a mistake to study only the expert and not the aids they use and the amount of information they require. By understanding the way experts make decisions, and the information required for them to make these decisions,

researchers hope to develop expert systems that "are based on codification of the knowledge and decision rules of experts" (Shanteau and Stewart, 1992, p. 101).

The domain of military command and control often involves complex decision making situations, uncertain information, and high-tempo tactical and operational environments. In these situations there is typically more than one correct answer to a problem. One characteristic that differentiates the novice from the expert is the timeliness of decisions made. Experts appear to be better at making decisions with information that is limited and ambiguous, entails a high degree of uncertainty, and is within a multidimensional battlespace. The ability to make these decisions has been effectively labeled as battle command decision-making expertise (Serfaty, et al., 1997).

1. Why Study Expert Decision Making

There are many different definitions for "experts." An expert is "one with the special skill or knowledge representing mastery of a particular subject." (Webster's, 1993) This definition provides the rationale for trying to determine if there is indeed a difference between recognized experts in the field of submarine TMA. Shanteau and Stewart (1992) state that there are at least three good reasons why research on expert decision makers is important: generalizing of differences between naïve subjects and experts; advancement of expert systems through examination of those running the system; and, experts are interesting in their own right.

a. Generality

It is not enough to assume there is a difference between recognized experts in a field of study, but to discover what exactly the differences are. During the course of a study if similar behaviors are observed between participants than an argument for the universality of the observed behavior can be made. The same goes for like behavior between participants in similar studies. For example, if the majority of experts and novices make decisions in a similar way then we can establish guidelines that represent behavior for all participants.

Analyses of experts provide an important means of establishing generality (Shanteau and Stewart, 1992). If there is a difference between the novice and expert participants then new guidelines need to be created. These guidelines will be broader in scope and will account for all observed participants in both studies and in the working environment.

b. Expert Systems

“Expert systems are based on the codification of the knowledge and decision rules of experts” (Shanteau and Stewart, 1992, p. 101). Studying experts is to capture the cognitive strategies they employ and use this understanding to develop tools to assist other decision makers (Shanteau and Stewart, 1992). Systems that fall under this category of “tools” are designed to assist experts in their decision making or to make decisions that are comparable to those made by their human counterparts.

The design of an expert system involves an in-depth study of how experts make their decisions. The analysis of experts will give us a greater understanding of when and where these systems can be used (Shanteau, 1992a). Expert systems should have most of the compiled knowledge that experts have. The knowledge and strategies employed by decision makers can be utilized to better represent data in expert systems. Experts and novices use data differently so the way in which data is presented is a challenge. These systems should be designed in a way that allows for flexibility in the processes employed to make decisions. Human experts are flexible; a rigid system would best be used to simulate novices (Shanteau, 1989).

c. Intrinsic Interest

Many researchers are intrigued by domain experts and want to know more about how they make decisions (Shanteau and Stewart, 1992, p. 102). If it were indeed true that the best decisions are made only by experts then it may be assumed that the novices would want to emulate experts. As a junior officer (novice submarine ship driver) this author always wanted to be like the senior officers (expert ship drivers). I was always interested in their thought processes during exercises and how they produce accurate solutions for COI through the TMA process.

The modern military relies on the judgments of expert decision makers to maintain a free state. Surface and sub-surface ship drivers, war planners, physicians, and even individual members of a platoon are expected to make expert decisions. These demands lead researchers to many unanswered questions such as: How good are these expert’s

decisions? Can their decision making skills be improved? What aids can be utilized to assist their decision making process?

2. Challenges in Examining Expert Performance

Identifying experts is the first challenge in conducting an experiment in this field of study (Edwards, 1992). Several approaches can be used to determine who qualifies as an expert (e.g., credentials). It may be that those in a particular domain should define the experts (Shanteau, 1992a), or that it takes one to know one (Edwards, 1992).

Once you have determined who the experts are, the second challenge is to gain access to them in order to study their decision making skills (Edwards, 1992). In order for experts to remain experts they must continually be involved in the field in which they work. This amount of upkeep may change drastically between different fields of study but, “If you don’t use it you lose it.”

The next, and last, challenge is to specify the measure of performance used to analyze the differences between participants (Edwards, 1992). All of the challenges discussed above may be overcome with some well considered planning prior to a given study.

3. Self-Efficacy

Self-efficacy is defined as the confidence level in an individual’s ability to execute courses of action or to achieve a desired outcome in the face of adversity (Bandura, 1997.) A low level of confidence will adversely affect the expected performance of an individual during

competition (Woodman and Hardy, 2003; Parfitt and Pates, 1999). There are several theories that explain this behavior. Bandura suggests that those individuals with high self-efficacy – the belief that one can achieve what one sets out to do - are confident, effective, and generally more successful than those individuals with low self-efficacy (Bandura, 1997).

Bandura suggests that self-efficacy judgments are derived from four sources: performance accomplishments; vicarious experiences; verbal persuasion; and emotional arousal (Bandura, 1997). It is the cognitive appraisal of the four sources of information that will either increase or decrease an individual's level of self-efficacy and subsequent confidence.

4. Cognitive Limitations of Experts

Intelligent people have great difficulty judging probabilities, making predictions, and otherwise, attempting to cope with uncertainty (Kahneman, Slovic, and Tversky, 1982). These challenging aspects of decision making problems are a key explanation for why humans rely on judgmental heuristics (Slovic, Fischhoff, and Lichtenstein, 1985; Kahneman, et al., 1982; Wickens, et al., 2004; Dry, et al., 2005). Although these heuristics are a functional tool used by the human brain to compensate for limited cognitive processing ability (Hutchins, 1996), they can lead to systematic biases and errors in judgment (Kahneman, et al., 1982). These heuristics (or mental rules of thumb) may explain both the high and low levels of performance observed when experts make decisions (Shanteau, 1988; Shanteau and Stewart, 1992).

Conducting TMA on individual contacts is a demanding task. In the submarine community there are several courses on what is called "mental gym." This headache inducing "gymnasium" involves the application of recognized formulas to a specified scenario in a limited amount of time without using a calculator. This work-out is the backbone of why submariners conduct ship operations safely.

5. Characteristics of Experts

Experts within similar domains may display similar psychological characteristics (Shanteau, 1988). Experts within a given domain may experience similar schools or training. All submarine officers attend similar schools during their careers. The thought process and analysis patterns between experts are similar; however, individual experiences sharpen the skill differently. The submariner TMA characteristics between experts are domain specific and will be similar because of the training requirements in their specified field. This section contains a brief description of some psychological traits relevant to the experts in this study. A more complete list can be reviewed in Shanteau (1987).

Experts generally have highly developed perceptual/ attention abilities (Shanteau, 1988). Few studies have shown how experts perceive uncertain data and how they produce effective decisions from those data. It takes time to perform both the studying and practicing portion to a particular trade. Any individual who has been practicing a trade for an extended period of time may qualify as an expert in that field. With practice experts become able to

extract information that the non-experts just do not notice to be relevant (Shanteau, 1988).

Experts have a sense of what is relevant and irrelevant (Shanteau, 1988). When experts are given too much information they should be able to sift through the data and rely on the relevant information only. Experts can determine relevant information because of the insight they have gained through experience in their fields (Shanteau, 1992b).

Experts have an ability to simplify complex problems (Shanteau, 1988). Breaking down the fundamentals of a game and making complex problems more simple, experts can then make better informed decisions. In the game of chess, recognized experts, have superior pattern recognition capabilities that allow them to perform better (De Groot, 1965).

Experts are able to handle adversity better than non-experts (Shanteau, 1988). Experts work better under stress and make better decisions. Given a scenario where there is uncertainty, the experts must determine relevant information (Shanteau, 1992b) to minimize mistakes in judgment.

6. Strategies of Decision Making Experts

While studying domain experts, many different strategies have been observed that lead to better decisions. Experts are able to make adjustments during the decision making process and generally avoid large mistakes (Shanteau, 1988). Domain experts use their experience to

continuously make decisions in an evolving situation several times over the course of a problem.

For example, as soon as expert Texas Hold-Em poker players realize that their hand is no longer the best one, they will fold it right away to save themselves money. The poker hand these “Pros” initially started with may have been the best one at the start of the round but by the time all the cards are showing on the table, their hands may be the worst. In this example, they must develop new decisions every time another card is exposed. They will produce solutions that lead to the least error or will save/make them the most money. “When you feel that you are beaten, it is time to toss your pretty cards into the muck. It may seem silly to think that folding may be a key in your poker progression, but saving chips that should've been lost is the exact same as winning chips” (Carlisle, 2006).

7. Is More Information Better for Expert Decision Makers?

A study regarding the amount of information required by experts while making decisions, conducted by Ettenson, Shanteau, and Krogstad (1987), provides an interesting approach to quantifying the amount of information used. Their study suggested that it was not necessarily the quantity of information used by experts, but the ability of the expert to focus on what information was relevant. Three groups of auditors were required to made judgments on thirty-two individual cases based on eight dimensions of accounting information. Results indicated that all three

groups relied upon three factors out of the eight in order to make their judgments, less than half of the factors that were available to each group.

The expert groups relied most heavily upon one single factor while other cues had secondary impacts. There was no single cue that was dominant for the novice participants. In conclusion, this study demonstrated that choosing to use less information was not a cognitive limitation but an indicator that the experts were able to focus on more relevant information. Novices appeared to require more information (Ettenson, et al., 1987; Shanteau, 1991). Although each participant was given a wealth of information, much of it was not required and did not add to the performance of the three groups.

In a later study, Shanteau states that “the amount of information used does not reflect degree of expertise; however, the type of information used does” (Shanteau, 1992b, p. 2). Shanteau also states that there is indeed a difference between mid-level and advanced experts because the advanced experts are better at evaluating which information is the most relevant (Shanteau, 1992b). A question for further research is to evaluate the differences in decisions made between different levels of expertise.

In support of Shanteau’s work, Omodei, McLennan, Elliott, Wearing, and Clancy (2005), state that more information is not necessarily better, especially given an adverse environment with uncertain conditions. The consensus is still the same when expert decision makers are confronted with an environment that is “time-pressured,

distributed, dynamic command environment characterized by uncertainty” (Omodei, et al., 2005, p. 39).

8. Battle Command Decision-Making

It is important to understand how an expert approaches a decision-making problem to better understand what we observe in the laboratory. The concept of “mental models” (Serfaty, et al., 1997), is used to further explain how experts step through a decision making experience.

In Figure 4, a five-step process is depicted in detail. Mental models are an internal interpretation of what we experience in the real world. As decision makers gain experience they ought to proceed through each step with a higher degree of certainty. Initially we would expect the expert’s pattern-indexed memory to construct a better mental model of the situation.

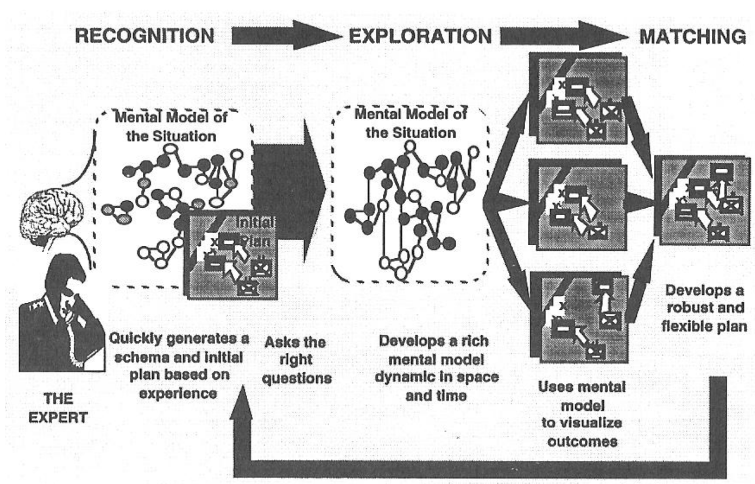

Figure 4. Five Step Process for “Mental Model” Analysis. (From: Serfaty, et al., 1997.)

In step 1, the expert may exhibit characteristics of a recognition-primed decision by generating an initial model

of what they have observing by recalling past experiences. In the next step, the expert formulates the right questions to ask in order to reduce uncertainty in his/her initial assumptions. This may be done in a time-constrained environment.

In step 3, the expert will now produce a model that is described as “rich” and “dynamic in space and time.” This is the mental model that the expert will use to produce several different outcomes in step 4 and develop a plan of action in step 5. The number of different outcome models is dependent on the experience level of the expert. As experience is gained in real world situations experts can produce many more possible outcomes and have more possible plans from which to choose.

Experts keep an extensive store of specific experiences in memory, supported by high-level principles taught in a classroom or on the job, that allow them to quickly develop a rough, still incomplete mental model for a new situation (Serfaty, et al., 1997). These models are typically built on sound principles learned by the expert over time. On any platform in the service, those individuals making decisions would expect some positive or negative feedback from individuals supporting them. If an experts mental model is wrong than he/she may require some feedback in order to transform their model into a more accurate one.

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III. METHODOLOGY

The purpose of this research was to determine if there is a difference in decision making expertise between three different groups of submarine TMA subject matter experts (SMEs) when using a graphical display that depicts the AOU for the scenario. The Java applicated, AOU study was used to simulate a submerged submarine scenario that involved several contacts of interest (COI). Each participant was required to formulate the best possible solution, specifically range, for one selected contact using the displayed AOU. The end result was to be either a satisfactory firing solution or coming to periscope depth.

The experiment included two scenarios, (i.e., targeting and navigation), and two color schemes for each scenario. One scenario had a bright center and dark edge, the other had a dark center and a bright edge. All scenarios had multiple contacts with at least one overlapping AOU.

Administering the four individual scenarios to each of the thirty participants (ten from each SME group), the hypothesis that there is a difference between the three SMEs can be tested. This chapter describes the process used to simulate the four scenarios, experimental design, participants, apparatus, procedure, and data collection.

A. EXPERIMENTAL DESIGN

The experimental task was to evaluate participants who observe a simulation of a submerged submarine which involved AOUs for several contacts. Each participant was

to formulate the best possible solution for a specific COI using the designated AOU. If there is a difference between experts it would be because of any confounding variables.

Two different scenario backgrounds were presented to each participant. In the first scenario each participant was to use the information presented by the AOU to evaluate the COI and report when they felt their solution was accurate enough to man battle stations and attack. In the second scenario each participant was required to use the information provided by the AOU to evaluate the COI and determine when it was safe for the submarine to proceed to periscope depth (PD).

Each of the scenarios required extensive calculations and application of the decision making process employed to conduct TMA by the participant. The only data provided were the uncertainty ellipses displayed in the specified AOU. Each scenario (attack and PD) had two different simulations available for a total of four different scenarios. Each participant engaged in all four scenarios as well as a practice scenario.

B. PARTICIPANTS

A total of 30 participants volunteered for the experiment. All were either U.S. Naval officers or enlisted submarine members. Two sites were visited in order to obtain enough individuals for each group of SMEs. Three CO/XO, eight DH, and ten FTs were participants in Groton, CT while all other participants were observed in Bangor, WA. Groton is known as the “submarine capital of the world” and is the home for many of the schools relating to the submarine service. The administering officer for

this study coordinated times for conducting the experiment that coincided with the participants schedules.

The CO/XO participants, on average, were ten years older than the FT participants and five years older than the DH participants. The CO/XO participants were also the most educated of all participants with 80% of them having received a Master’s Degree.

1. FT Participants

FT participants were selected using two criteria. First, each participant had to be a second class petty officer or above. Second, each participant had to have been an instructor at a FT school. The reason for these criteria was to ensure that the participants from this group had enough experience in the field of TMA to be considered an Expert. FT participant ages ranged from 26 to 37 years, with the average age being 33.7 years.

2. DH Participants

The Submarine Officer Advanced Course (SOAC) was the main source for the DH participants. Upon graduation from SOAC these Lieutenants proceed to the fleet to become Navigator, Weapons, or Engineering officers onboard submarine platforms. The DH participants from SOAC had yet to serve as an actual DH on a submarine. Several DH participants had already served as a DH on a submarine. DH participant ages ranged from 26 to 37 years, with the average age being 29.3 years.

3. CO/XO Participants

The CO/XO participants were selected using one criterion. The CO/XO participants had to have graduated from the Pre-Executive Officer School (PXO). Two of the CO/XO participants recently graduated from the PXO course while the rest of the CO/XO participants were stationed on submarines or had completed their submarine tour as a CO or XO. CO/XO participant ages ranged from 34 to 44 years, with an average age of 39 years.

C. APPARATUS

1. Laptop Computer

The test apparatus consisted of a Pentium II 2GHz laptop computer. The laptop computer was placed on a standard sized desk with normal lighting conditions. Figure 5 depicts a demonstration of how a participant may have conducted the experiment. The exact location for each participant varied. Participants observed the scenarios from their work offices, hotel rooms, or in one case, their own home.

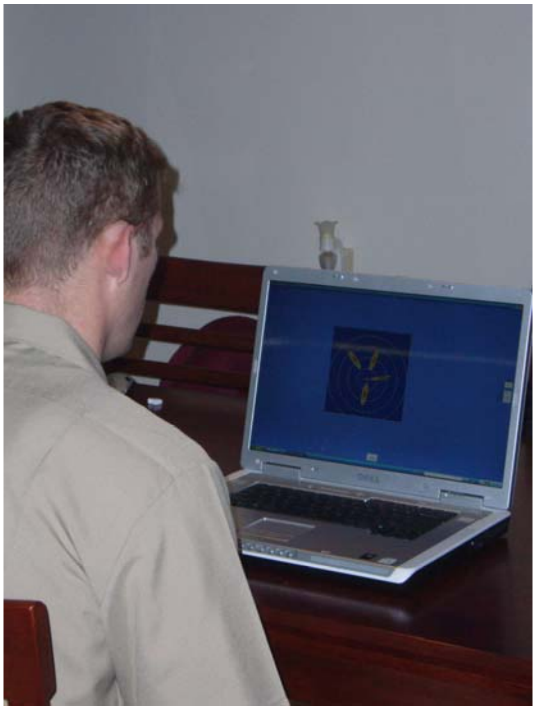

Figure 5. Example of the Experimental Setup.

2. Surveys

Four different surveys were completed by each participant. All of the surveys were designed by this author and his advisor with the exception of the NASA Task Load Index (TLX) survey.

a. Biographical Data Survey (Appendix A)

The goal of this survey was to collect basic information such as rank, rate, age, etc.

b. Scenario Survey (Appendix B)

The goal of this survey was to collect participant solutions for the scenarios and to determine what characteristics influenced his problem solving.

c. NASA Task Load Index (Appendix C)

The TLX is a subjective workload assessment tool. It is compromised of six subscales that measure Mental Demand, Physical Demand, Temporal Demand, Effort, Performance, and Frustration.

d. Post-Scenario Questionnaire (Appendix D)

The goal of this questionnaire was to gather information that may have affected the decision making of the participants during the experiment. The information obtained from these questionnaires will be used when designing future submarine displays.

D. PROCEDURE

1. Surveys

Upon arrival, participants were required to read and sign the consent form in APPENDIX F. The protocol used to perform the testing is in APPENDIX E. In order to ensure each participant experienced the same situation the written protocol form in APPENDIX E was used by the administering officer. Participants were provided an overview of the study as well as being informed that their data would be compared with two other groups of participants representing two other groups of experts. The researcher explained that a 95% ellipse for a given contact meant that the contact had a probability that it was located within that particular ellipse 95% of the time and outside the ellipse 5% of the time.

Participants then observed the practice scenario to familiarize themselves with the format and to provide them

with examples of ellipses. The administering officer used Appendix E in order to fully explain the format of the GUI display and controls. Participants were given as much time as necessary to ask questions and ensure they were comfortable with the display format.

Once a scenario began it could only be stopped when the participant conducted the TMA and produced a solution for the COI. If the participants did not manually stop the scenario by selecting the stop button (see Figure 10 ellipse C) then the screen would go blank and he would be required to report his solution (this happened six times).

Appendix B contains the four scenario examples. The scenarios were presented in a partially randomized manner. The order was limited to a total of eight different sequences. Scenarios One and Three were similar with the exception that Three was skewed 228 degrees. Scenarios Two and Four were similar with the exception that Four was were skewed 62 degrees. To prevent the participant from noticing a similarity between any skewed scenario pair, no paired scenarios were presented back-to-back.

Upon completion of each scenario, participants filled out Appendices B and C. Each Scenario Survey requested a Range, Range +/-, Bearing, Bearing +/-, Course, and Course +/-. Several questions pertained to the weight individuals placed upon certain factors during their decision making. For example, on a scale from one to ten (ten being the most important) how much did the safety of the ship weigh in your decision?

As stated above, the NASA Task Load Index (Appendix B) was completed after each scenario. The same sheet of paper

was used for all four scenarios. When a participant placed a mark on the scale he would use the scenario number as a mark. For example, if the participant felt a high level of Mental Demand for scenario Three then he would mark a three on the scale close to the high end of the scale. On a subsequent scenario, if the participant felt the same level of mental demand then he would place that scenario number at the same place on the scale.

Upon completing all four scenarios and all of the surveys attached to those scenarios, the participants completed the Post Scenario Survey (Appendix D). The Post Scenario Survey assessed the overall experience from each participant for all four scenarios. These questions focused on the confidence level of each participant in using an AOU to assess range estimates and the participant’s experience with regard to TMA decision making.

2. Scenarios

The process of generating scenarios was extensive. The same format used by Kirschenbaum and Arruda (1994) was used in the current research. A meeting between the author, Susan Kirschenbaum, Wendy Berube, and Sandie Grage was conducted at NUWC several months before the experiment was conducted. The JAVA coded simulation was provided by Ms. Berube and the displays were produced by Ms. Sandie Grage. Susan Kirschenbaum provided the background information displayed within the scenarios (AOU color and information format).

a. JAVA Simulation Code

The Java simulation code consists of three files: Main.java, AouJFrame.java, and ImagesFrame.java. Main.java is the class that is called first and instantiates the AouJFrame class. Once the AouJFrame is instantiated, all the components (panels, text, labels, buttons, etc) for the graphical user interface (GUI) are displayed and initialized. The AouJFrame file also includes the methods for opening the output file once the enter button is selected and writing output data to it when the stop button is selected. Lastly, this file contains methods to write the ownship and target position data which corresponds to the displays which depict the AOUs for the targets. The ImagesFrame.java file first creates a background thread to improve efficiency and then displays the AOU displays sequentially every 10 seconds. The Java class MediaTracker includes built-in functions which handle displaying images.

b. Displays

The four scenarios used during the research were generated from two initial scenarios. Each initial scenario was skewed either 228 or 62 degrees for the odd and even scenarios respectively to produce a total of four scenarios. Ms. Sandie Grage and some military advisors generated the geometries for the two scenarios. These scenarios were created by a hypothetical periscope and targeting scenario whiteboard discussion. Once the scenarios were generated, the information (such as target initial bearing, range, course, speed, and ownship maneuvers) was given to a technician who coded the scenarios in a TI-04 simulator.

The scenarios were run through the TI-04 system and the outputted data were collected. Data extracted from the collected output were placed into a functional database and then a Matlab script was created to extract information for ownship, target, and AOU data. A state estimation algorithm, Nodestar, was used to calculate contact solutions for the scenarios. A Matlab script was used to convert the extracted information and draw the display figures. The displays were drawn and depicted ownship position, each target's position, each target's AOU, and range rings.

c. Scenario Generation

To run the Java application, a Java Software Development Kit (SDK) was installed on a laptop computer. All files for the program were stored in a folder for easy access before and after the scenarios were run. Before each scenario was run, the participant number and the scenario was entered into the file name section of Figure 6. For example, “001TarYelNov25DH” would be the file name for the first participant, targeting scenario with the yellow centered AOU, administered on the 25th of November, to a department head SME.

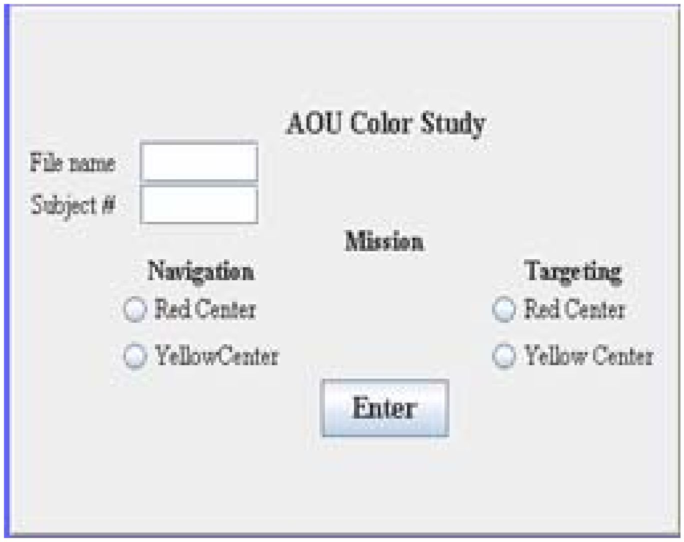

Figure 6. Mission Selector for the AOU Study.

To begin each scenario, after entering the file name and selecting a mission, the administering officer would select the enter button in Figure 6. The scenario would begin and display a new display every ten seconds. When a satisfactory solution for the COI was determined by the participant, he stops the scenario by selecting the stop button in Figure 10, ellipse C. When the stop button was selected the following information was saved in a specified file location: scenario, subject number, start time, and stop time.

d. Scenario Description

A total of four scenarios were generated for the present research. Appendix B contains the four handouts given to the participants before each of the four scenarios. The Yellow Centered Targeting Mission was scenario One. The Yellow Centered Navigation Mission was scenario Two. The Red Centered Targeting Mission was scenario Three. The Red Centered Navigation Mission was

scenario Four. Although there were multiple AOUs in each scenario, each participant was instructed to analyze only the AOU assigned to the COI.

Each scenario included a total of ninety individual displays. The GUI formatted, JAVA coded program presented each display to the participant in a specified order that simulated the motion of all contact's AOUs. All contact AOUs originated in the center of the screen and within the first minute of each scenario the AOUs would steadily migrate out to a realistic location. Each participant was told that they must wait for the first two minutes of each scenario (which included 12 slides) before they could begin trusting the AOU data locations.

Figure 7 is an example of a yellow centered AOU display. Figure 8 is a red centered AOU display that is similar to the display in Figure 7 with the exception that it is skewed sixty-two degrees to produce a different even scenario. In Figure 7 there are five individual AOUs present. Each AOU is labeled S1 through S5 respectively and each AOU has several different probability ellipses available for evaluation. Different colors are used to indicate probabilities that the contact is located inside that AOU. The red ellipse indicates there is a 95% probability that S4 is located within the red and yellow rings combined. The yellow ellipse represents a 66% probability that S4 is located in the yellow ring only.

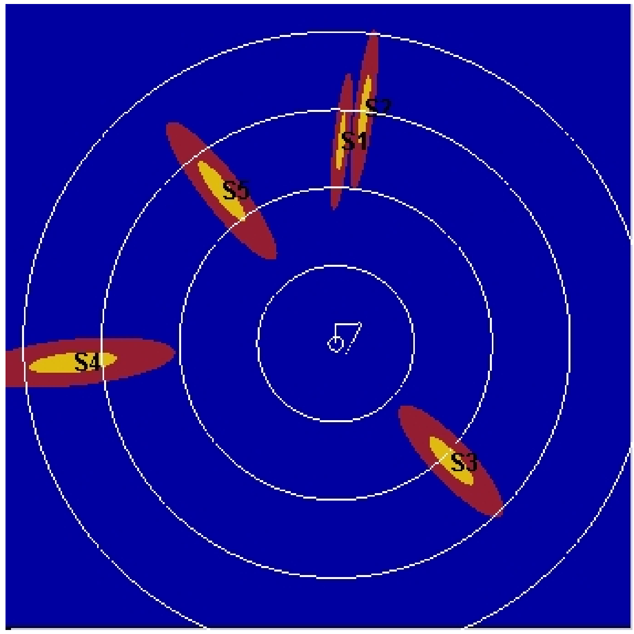

Figure 7.   Yellow Centered AOU Scenario Display.

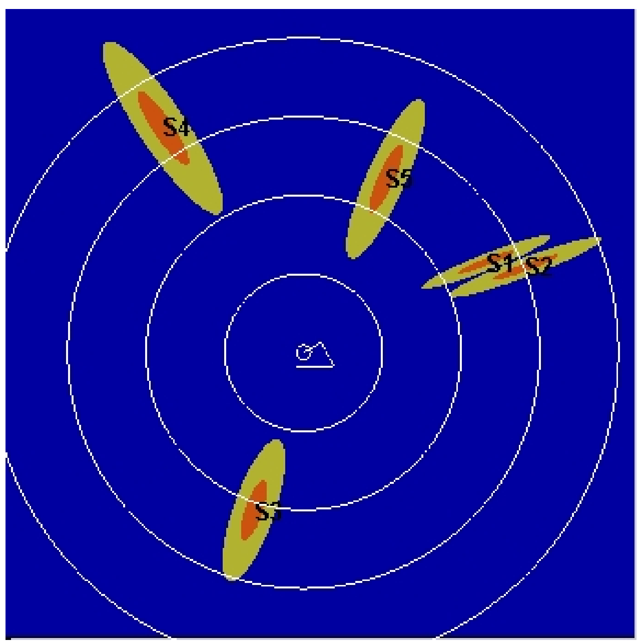

Figure 8.   Red Centered AOU Scenario Display.

Relative motion was simulated by the Java coded program displaying subsequent displays during a scenario. Figure 7 and Figure 9 depict examples of subsequent displays. Figure 7 would be displayed first and ten

seconds later Figure 9 would be displayed. When reviewing the two displays notice the difference in S4’s location. In Figure 7, the right edge of S4’s AOU is positioned at the ten thousand yard range ring. In Figure 9 the right edge of S4’s AOU is now positioned half way between the ten thousand and five thousand yard range rings. This difference between Figure 7 and Figure 9 would simulate S4 moving toward the center of the screen.

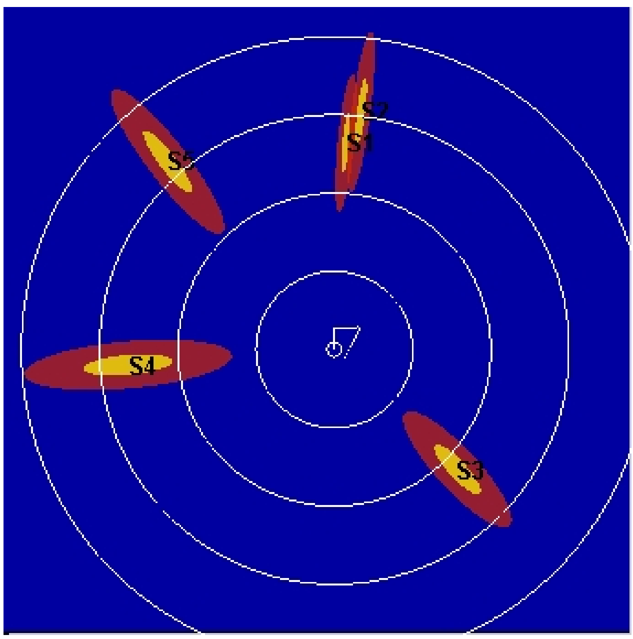

Figure 9. Yellow Centered AOU Scenario Display Subsequent to the Jpeg in Figure 7.

e. Practice Scenario

A practice scenario allowed participants to familiarize themselves with the controls of the program and the simulation format. The practice scenario included an in-depth explanation of the controls and setup of the program. This practice scenario was similar to that used

by Kirschenbaum and Arruda (1994) and was essentially a walk through by the administering officer.

Figure 10 is a screenshot of the practice scenario that was viewed by each participant. The simulated ownship marker during all scenarios was at the center of the screen. Four range rings, valued at five thousand yards apiece, for a total of twenty thousand yards surrounded the ownship marker. Ellipse A, in Figure 10, is an enlarged ownship marker at the center of the screen.

Ellipse B in Figure 10 is an enlarged display of ownship speed and course, as well as a COI solution generated by a fire control computer is shown. The generated fire control solution was explained to each participant as a solution that would be generated by a fire control technician onboard a submarine while underway. This generated solution was not to be considered as truth but more of an assistant to the participant.

Ellipse C in Figure 10 is an enlarged stop button. When the participant was comfortable with his solution for the COI he was instructed to click on the stop button using the mouse pointer. Each participant was toldto remember his COI solution before selecting stop because when the stop button was selected the screen would disappear.

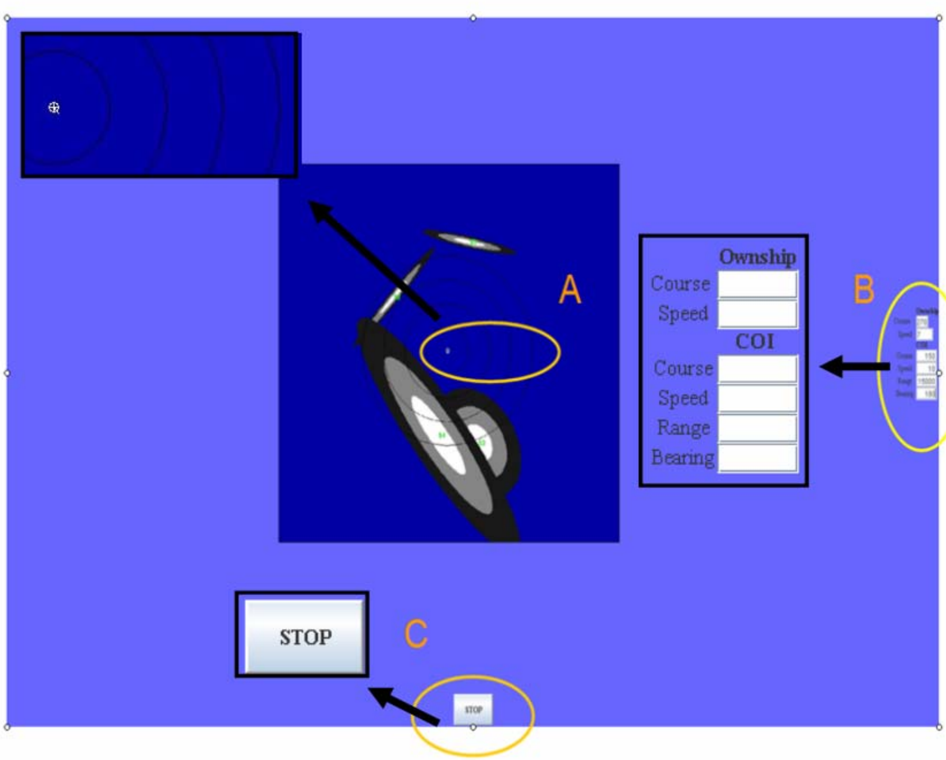

Figure 10. Example of the Practice Scenario Screenshot with Individual Sections Outlined and Magnified.

E. DATA ENTRY AND FORMATTING

The data (Appendix B) needed to be transformed prior to analysis. Data formatting for expertise, time, and range are described in the following sub-sections. The corresponding data are provided in Appendices M through P.

1. Expertise

SMEs were grouped based on their level of expertise. The SMEs were FTs (Group One), DHs (Group Two), and COs/XOs (Group Three). With ten participants in each group, therewere 30 data points for each scenario. The three different groups of expertise were recorded in the expert column of Appendices M through P.

2. Time

The length of time each participant took to complete a scenario required two conversions in order to analyze the data correctly. The first conversion required the output of the Java program to be rounded down to the nearest ten seconds. This rounding was done because each new display was presented in ten seconds increments during the scenario. If a participant selected the stop button at 00:10:45 (ten minutes and forty five seconds) then he based his solution on the display at 00:10:40 (ten minutes and forty seconds). The second conversion was required to convert a 00:00:00 formatted time into a number with three decimal places. For example, 00:07:40 would convert to 7.667 minutes. This converted time is recorded in the time column of Appendices M through P.

3. Range

The range data lists what each participant believed the correct range to the COI was at the time he stopped the scenario. Range differences were calculated by comparing the reported range for the COI by the participant to the actual range of the contact. These ranges were recorded in thousands of yards (Kyards). Column five was used for the analysis of range differences between different levels of expertise in Appendices M through P.

The range +/-, within range, over or under variables in columns four, six, and seven, respectively, were also used to analyze how accurate the different experts were in estimating ranges for the COI. The range +/- variable requires the participant to calculate an acceptable variability in range estimates for the COI. A relatively

large range envelope would be an advantage over one with smaller range envelope. For example, a range envelope that is four miles long has a greater probability of encompassing the COI than a range envelope that is one mile. The over or under variable represents a participant's response that was an over-estimated range.

4. Example of Data Formatting

A reported range estimate of 10.0 Kyards (10,000) with a variable range +/- equal to 3.0 Kyards (3,000) at time 00:10:40 would represent a total range envelope between 7.0 Kyards (7,000) and 13.0 Kyards (13,000). The COI, in this example, is located at 11.0 Kyards (11,000) from ownship. The calculated range difference would be 1.000 Kyards (1000). In Appendices M through P, a “1” is listed for the within range variable because the COI was located within the range envelope. Since the reported range of 10,000 yards is less than the actual range of 11,000 yards a “0” is listed for the over or under variable because the COI the range estimate was an under-estimated range.

IV. RESULTS AND ANALYSIS

A. OVERVIEW

This section outlines the statistical analyses performed on the data. Section B describes the formatting required to analyze the data. Section C provides the analysis of the scenarios. Table 1 is an example of how the data are summarized for each section's analysis.

Scenario X				
	CO/XO	DH	FT	P-Value
Time (minutes)				
Range (Kyards)				
Within Range				
Range Envelope (Kyards)				
Over or Under				

Table 1. Example of How Data are Presented for each Scenario.

Several surveys were used to acquire the data to be analyzed. Biographical data are reported in Appendix A. Appendix B includes the performance data on all four scenarios. Appendix C includes the NASA Task Load Index (TLX) which used to assess the workload of the participants.

Hypothesis 1 states there is a difference between the groups of SMEs with respect to their ability to estimate ranges to a COI when presented with uncertain data. Performance of the three groups was compared on the following variables: time to estimate range, range estimations, the proportion of ranges that were within a specified range envelope, and whether or not a range estimate was over-estimated or under-estimated.

B. RESULTS

1. Scenario I

Scenario One was a time sensitive scenario. No differences between the experts were noted. Appendix B describes the scenario in detail; Appendix K contains the TLX and personal preferences for all participants. Table 2 provides a summary of the Scenario One data.

Scenario One				
	CO/XO	DH	FT	P-Value
Time	7.06	9.067	9.617	
Range	1.310	0.876	1.731	> .05
Within Range	5	6	3	> .05
Range Envelope	0.88	0.95	1.025	> .05
Over or Under	4	3	3	> .05

Table 2. Mean Performance Data for Three Groups of Experts for Scenario One.

a. Time Comparison for Groups of Experts

A test for equal variance revealed that the data was not normally distributed (Bartlett's Test: test statistic = 6.18, $p < .05$). A boxplot in Figure 11 presents variances between groups of experts. The CO/XO SMEs completed Scenario One fastest while reporting the lowest time constraint pressure on the NASA TLX. The CO/XO group reported a mean of 5.5 (out of 10). The mean time pressure for all participants was 6.9.

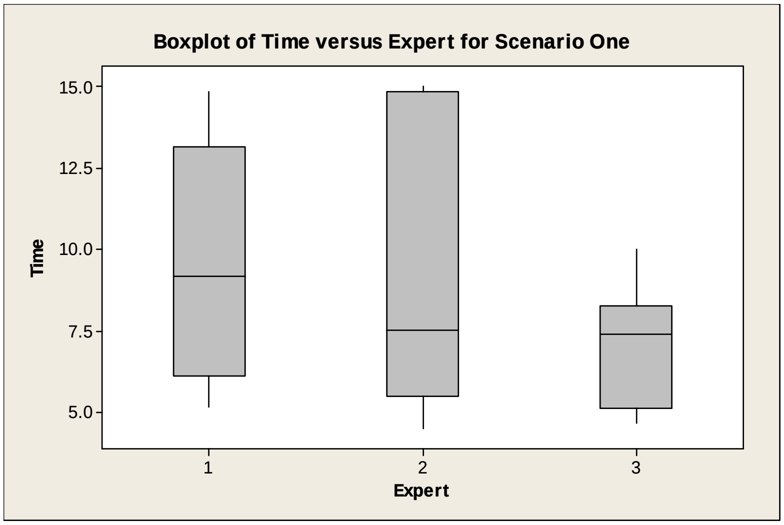

Figure 11. Boxplot of Time versus Expert for Scenario One

b. Range Difference Comparison for Groups of Experts

A test for equal variance revealed that the data was normally distributed (Bartlett's Test: test statistic = 3.51, p > .05). A one-way ANOVA revealed there were no significant differences between expert groups regarding estimating ranges to a COI $F(2,29)=.23$, p > .05. There is one range difference (highlighted on Appendix M) that is three standard deviations from the mean, therefore, is considered an outlier. A second one-way ANOVA produced similar results. Expertise was not a factor when estimating ranges to a COI, $F(2,29)=1.25$, p > .05.

The DH SMEs reported COI solutions with the least amount of range difference. DH experts reported ranges that were approximately 400 and 800 yards more accurate than the CO/XO and FT experts, respectively. The DH experts also reported the lowest personal experience (5.1 out of 10) and confidence in solution (1.4 out of 4) on Appendix B's personal traits section. See Appendix K for

details. The overall means for personal experience and confidence in solutions were 6.0 and 2.0, respectively.

c. Within Range Comparison for Groups of Experts

The DH and CO/XO experts reported range envelopes that contained the COI 50% of the time or better. The FT experts report range envelopes that contained the COI 30% of the time. Regression was used to determine if there was a significant difference between expert groups with regard to reporting a range envelope that contained the COI. There was no evidence that expertise was a factor in range envelope accuracy (test that all slopes are zero: G = 0.809, df = 1, $p = 0.368$).

d. Range Envelope Comparison for Groups of Experts

A one-way ANOVA revealed there was no significant difference between expert groups regarding the size of range envelope estimates for the COI $F(2,29)=.26$, $p > .05$.

e. Over or Under Estimate Comparison for Groups of Experts

The DH and FT expert groups over-estimated the range to the COI 30% of the time while the CO/XO expert group overestimated the range to the COI 40% of the time. Regression was used to determine if there was a significant difference between expert groups regarding reported over-estimated or under-estimated ranges to the COI. There is no evidence that expertise was a factor in over-estimating or under-estimating ranges to a COI (test that all slopes are zero: G = 0.226, df = 1, $p = 0.635$).

2. Scenario II

Scenario Two was not as time intensive as both Scenarios One and Four. No differences between the experts were noted. Appendix B describes the scenario in detail; Appendix L contains the TLX and personal preferences for all participants. Table 3 provides a summary of the Scenario Two data.

Scenario Two	CO/XO	DH	FT	P-Value
Time	4.614	6.047	5.583	> .05
Range	4.355	3.968	4.786	> .05
Within Range	2	3	1	> .05
Range Envelope	2.49	2.35	2.1	> .05
Over or Under	0	1	0	> .05

Table 3. Mean Performance Data for Three Groups of Experts for Scenario Two.

a. Time Comparison for Groups of Experts

A test for equal variance revealed that the data was normally distributed (Bartlett’s Test: test statistic = 1.25, $p > .05$). A one-way ANOVA revealed there were no significant differences between expert groups regarding the length of time it took for them to generate their COI solutions $F(2,29)=.78$, $p > .05$. The CO/XO SMEs completed Scenario Two fastest while reporting the lowest time constraint pressure on the NASA TLX. The CO/XO group reported a mean of 5.6 (out of 10). The mean time pressure for all participants was 5.7.

b. Range Difference Comparison for Groups of Experts

A test for equal variance revealed that the data was normally distributed (Bartlett’s Test: test statistic =

1.81, $p > .05$). A one-way ANOVA revealed there were no significant differences between expert groups regarding estimating ranges to a COI $F(2,29)=.39$, $p > .05$.

The DH SMEs reported COI solutions with the least amount of range difference. DH experts reported ranges that were approximately 400 and 800 yards more accurate then the CO/XO and FT experts, respectively. The DH experts also reported the lowest personal experience (5.5 out of 10) and confidence in solution (2.1 out of 4) on Appendix B’s personal traits section. See Appendix L for details. The overall means for personal experience and confidence in solutions were 6.2 and 2.3, respectively.

c. Within Range Comparison for Groups of Experts

The DH and CO/XO experts reported range envelopes that contained the COI 30% and 20% of the time, respectively. The FT experts report range envelopes that contained the COI 10% of the time. Regression was used to determine if there was a significant difference between expert groups with regard to reporting a range envelope that contains the COI. Approximately 20% of the total participants reported range envelopes that contained the COI. There was no evidence that expertise was a factor in range envelope accuracy (test that all slopes are zero: G = 0.314, df = 1, $p = 0.575$).

d. Range Envelope Comparison for Groups of Experts

A one-way ANOVA revealed there was no significant difference between expert groups regarding the size of range envelope estimates for the COI $F(2,29)=.28$, $p > .05$.

e. Over or Under Estimate Comparison for Groups of Experts

Regression was used to determine if there was a significant difference between expert groups regarding reported over-estimated or under-estimated ranges to the COI. One participant over-estimated the range to the COI. There is no evidence that expertise was a factor in over-estimating or under-estimating ranges to a COI (test that all slopes are zero: G = 0.000, df = 1, p = 1.000).

3. Scenario III

Scenario Three was not as time intensive as both Scenarios One and Four. One difference between the experts was noted. A difference between DH and FT SMEs is accuracy of range envelopes. Appendix B describes the scenario in detail; Appendix M contains the TLX and personal preferences for all participants. Table 4 provides a summary of the Scenario Three data.

Scenario Three				
	CO/XO	DH	FT	P-Value
Time	8.213	8.344	9.53	> .05
Range	1.603	1.082	1.654	> .05
Within Range	3	5	1	< .05
Range Envelope	0.965	1.05	0.9	> .05
Over or Under	3	3	2	> .05

Table 4. Mean Performance Data for Three Groups of Experts for Scenario Three.

a. Time Comparison for Groups of Experts

A test for equal variance revealed that the data was normally distributed (Bartlett's Test: test statistic = .58, p > .05). A one-way ANOVA revealed there were no significant differences between expert groups regarding the

length of time it took for them to generate their COI solutions $F(2,28)=.45$, $p > .05$. The CO/XO SMEs completed Scenario Three fastest while reporting the lowest time constraint pressure on the NASA TLX. The CO/XO group reported a mean of 5.1 (out of 10). The mean time pressure for all participants was 5.9.

b. Range Difference Comparison for Groups of Experts

A test for equal variance revealed that the data was normally distributed (Bartlett's Test: test statistic = 2.09, $p > .05$). A one-way ANOVA revealed there were no significant differences between expert groups regarding estimating ranges to a COI $F(2,29)=.23$, $p > .05$.

The DH SMEs reported COI solutions with the least amount of range difference. DH experts reported ranges that were approximately 600 yards more accurate than the CO/XO and FT experts. The DH experts also reported the lowest personal experience (4.1 out of 10) and confidence in solution (1.5 out of 4) on Appendix B's personal traits section. See Appendix M for details. The overall means for personal experience and confidence in solutions were 5.4 and 1.9, respectively.

c. Within Range Comparison for Groups of Experts

The DH experts reported range envelopes that contained the COI 50% of the time while CO/XO experts reported range envelops that contained the COI 30% of the time. Regression was used to determine if there was a significant difference between expert groups with regard to reporting a range envelope that contains the COI. There

was no evidence that expertise was a factor in range envelope accuracy (test that all slopes are zero: G = 0.963, df = 1, p = 0.326), however, the goodness-of-fit tests revealed that there was sufficient evidence for the model not fitting the data adequately. Three additional regressions were analyzed with regard to reporting range envelopes that contain the COI.

A regression between expert groups one and two revealed there is a difference regarding range envelope accuracy (test that all slopes are zero: G = 4.070, df = 1, p = 0.044). A regression between expert groups two and three revealed there is no difference regarding range envelope accuracy (test that all slopes are zero: G = 0.840, df = 1, p = 0.359). A regression between expert groups one and three revealed there is no difference regarding range envelope accuracy (test that all slopes are zero: G = 1.297, df = 1, p = 0.255).

d. Range Envelope Comparison for Groups of Experts

A one-way ANOVA revealed there was no significant difference between expert groups regarding the size of range envelope estimates for the COI $F(2,29)=.15$, $p > .05$. There is one range envelope (highlighted on Appendix M) that is three standard deviations from the mean, therefore, is considered an outlier. The participant who recorded the range envelope outlier also scored a range difference of 3.962. No further analysis was done because the larger range envelope did not provide any benefit to the participants within range results.

e. Over or Under Estimate Comparison for Groups of Experts

All three experts over-estimated the range to the COI approximately 30% of the time. Regression was used to determine if there was a significant difference between expert groups regarding reported over-estimated or under-estimated ranges to the COI. There is no evidence that expertise was a factor in over-estimating or under-estimating ranges to a COI (test that all slopes are zero: G = 0.257, df = 1, p = 0.613).

4. Scenario IV

Scenario Four was a time sensitive scenario. One difference between the experts was noted. No differences between the experts were noted. Appendix B describes the scenario in detail; Appendix N contains the TLX and personal preferences for all participants. Table 5 provides a summary of the Scenario Four data.

Scenario Four	CO/XO	DH	FT	P-Value
Time	4.844	2.933	4.747	> .05
Range	5.097	3.772	4.976	> .05
Within Range	1	4	1	> .05
Range Envelope	2.35	2.17	1.95	> .05
Over or Under	0	2	0	> .05

Table 5. Mean Performance Data for Three Groups of Experts for Scenario Four.

a. Time Comparison for Groups of Experts

A test for equal variance revealed that the data was normally distributed (Bartlett’s Test: test statistic = 2.96, p > .05). A one-way ANOVA revealed there were no significant differences between expert groups regarding the

length of time it took for them to generate their COI solutions $F(2,29) = 1.74$, $p > .05$. The DH SMEs completed Scenario Four fastest. The DH group reported a mean of 7.7 (out of 10). The mean time pressure for all participants was 7.7.

b. Range Difference Comparison for Groups of Experts

A test for equal variance revealed that the data was normally distributed (Bartlett's Test: test statistic = 1.43, $p > .05$). A one-way ANOVA revealed there were no significant differences between expert groups regarding estimating ranges to a COI $F(2,29) = 1.09$, $p > .05$.

The DH SMEs reported COI solutions with the least amount of range difference. DH experts reported ranges that were approximately 1300 and 1200 yards more accurate then the CO/XO and FT experts, respectively. The DH experts also reported the lowest personal experience (4.3 out of 10) and confidence in solution (1.7 out of 4) on Appendix B's personal traits section. See Appendix N for details. The overall means for personal experience and confidence in solutions were 5.7 and 2.0, respectively.

c. Within Range Comparison for Groups of Experts

The DH experts reported range envelopes that contained the COI 40% of the time and the CO/XO and FT experts reported range envelops that contained the COI 10% of the time. Regression was used to determine if there was a significant difference between expert groups with regard to reporting a range envelope that contains the COI. There

was no evidence that expertise was a factor in range envelope accuracy (test that all slopes are zero: G = 2.532, df = 1, p = .112).

d. Range Envelope Comparison for Groups of Experts

A one-way independent ANOVA indicates there were no significant differences between expert groups regarding the size of range envelope estimates for the COI $F(2,29)=.22$, $p > .05$.

e. Over or Under Estimate Comparison for Groups of Experts

Regression was used to determine if there was a significant difference between expert groups regarding reported over-estimated or under-estimated ranges to the COI. Two participants over-estimated the range to the COI. There is no evidence that expertise was a factor in over-estimating or under-estimating ranges to a COI (test that all slopes are zero: G = 0.000, df = 1, p = 1.000).

5. Experiment Progression

a. Range Difference Comparison as the Experiment Progressed

The analysis in this section does not consider the participants. The participant scores were combined for each scenario progression. A test for equal variance revealed that the data was normally distributed (Bartlett's Test: test statistic = 2.60, $p > .05$). A one-way ANOVA revealed there were no significant differences between scenarios as the experiment progressed regarding range estimations $F(3,119)=.40$, $p > .05$. This result is contrary

to any assumption that the participants range estimation should get better as they experience more AOU scenarios.

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V. SUMMARY, DISCUSSION, AND RECOMMENDATIONS

A. SUMMARY

There is no significant difference between the expert groups when it came to generating range solutions to a COI. There was a significant difference between the DH and FT expert groups within range estimates.

B. DISCUSSION

1. No Range Accuracy Significant Difference

While the sample of DH experts in the current study reported more accurate range estimates than the other two expert groups, this difference was not statistically significant. It is possible that AOUs do not provide enough information for SMEs to develop solutions that are significantly different. All officers receive the same TMA training during their careers. Logically the CO/XO SMEs should report more accurate ranges to a COI when given similar conditions as the DH and FT SMEs.

Shanteau has done extensive research in the behavior of experts. Experts within similar domains display similar psychological characteristics and have a sense of what is relevant or irrelevant (Shanteau, 1988). Shanteau also states that there is indeed a difference between mid-level and advanced in that the advanced experts are better at evaluating which information is the most relevant (Shanteau, 1992b).

No differences between SMEs were observed because AOUs alone do not provide enough information to develop solutions that are representative of the expert’s ability.

The AOU provides a minimal amount of data with a high degree of uncertainty. The solutions generated by the SMEs are just as uncertain as the data from which they were generated. AOUs that are accompanied by additional information such as bearing rate and bearings would be a better use of an expert's TMA abilities.

2. Range Envelope Significant Differences

A significant difference was noted between the DH and FT experts regarding the ability to develop range envelopes that contain the COI. The DHs were able to generate ranges to the COI that were 800 yard more accurate than the FT experts. The DHs utilization of a slightly larger range envelope (1.63 Kyards) when compared to the FT experts (1.49Kyards) along with their more accurate range estimations is the reason for the significant difference.

C. RECOMMENDATIONS

1. Future Decision Aids

The results of the current study demonstrate that there are no differences between SMEs regarding range accuracies given an AOU so any decision aid produced would be applicable to all users, regardless of their expertise. The information obtained in the post scenario questionnaire (Appendix D) is invaluable in the development of a new decision aid. Two examples of requested information that could be displayed with an AOU is bearing rate and AOU history. Bearing rates are a key ingredient in understanding relative motion between a COI and ownship. AOU history provides a track of the COI's relative motion.

2. Future Studies

I recommend a study that presents a COIs bearing rate, bearing, AOU, and AOU history to expert groups to those used in the current study. The recommended study should have more than ten participants in each expert group. The requirements for these participants should meet or exceed the requirements used in the current study. It is suggested that "the amount of information used does not reflect degree of expertise; however, the type of information used does" (Shanteau, 1992b, p. 2). In this future study more information would be presented to three groups of SMEs allowing for results that may or may not support the findings in the current study.

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APPENDIX A: BIOGRAPHICAL DATA

Biographical Data. Subject #_____

1. Age:

2. Education	Year	Degree	Major
High School:			
Under graduate:			
Graduate:			
Post graduate:			

3. Navy Experience

Rank

Years in the Navy

Time at sea (Months)

Time since last sea tour (Months)

4. Combat Systems

List the combat Systems you have most recently used Dates used

5. Add any other relevant experience you feel may have affected your results. For example, being an Instructor or having a lot of experience in high density areas while being submerged.

6. List schools attended that have developed your TMA skills.

7. Are you Introverted or Extroverted? _______________

8. Email address __________________________

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APPENDIX B: FOUR SCENARIOS

Scenario 1

In this scenario you are required to proceed to PD in an expeditious way. The submarine is required to receive the next broadcast and you must use caution, but at the same time proceed as quickly as possible. Stop the scenario once you are ready to proceed to PD.

What was your final solution for the COI?

Range + or - , Bearing + or - , Course + or -

Using a range between 1 and 10 (10 being the most), to answer how much each factor weighed in your decision making.

Safety of ship _____ (Do not want to sink the ship)

Job Satisfaction _____ (You have trained hard so show it)

Job Security/ Promotion _____ (Do not want to be relieved or demoted for collision)

Letting down the team _____ (Everyone is counting on you to make a good decision)

Mission Accomplishment _____ (Be the best boat on the waterfront)

Personal Satisfaction _____ (You do everything well, even taking out the trash)

Time Constraint _____ (The ship needs to get to PD in a hurry)

Personal Experience _____ (You have seen this stuff a million times)

How confident were you in your ability to compute a solution given the AOU data?

|______________|______________|______________|______________|

Not Confident	Mildly Confident	Confident	Very Confident	Extremely Confident

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Scenario 2

In this scenario you are required to proceed to PD. Consider this trip to be a routine visit to receive the broadcast, ventilate, and train. The submarine's only threat is collision and the CO tells you to get us there as soon as you feel comfortable. Stop the scenario once you are ready to proceed to PD.

What was your final solution for the COI?

Range + or - , Bearing + or - , Course + or -

Using a range between 1 and 10 (10 being the most), answer how much each factor weighed in your decision making.

Safety of ship _____ (Do not want to sink the ship)

Job Satisfaction _____ (You have trained hard so show it)

Job Security/ Promotion _____ (Do not want to be relieved or demoted for collision)

Letting down the team _____ (Everyone is counting on you to make a good decision)

Mission Accomplishment _____ (Be the best boat on the waterfront)

Personal Satisfaction _____ (You do everything well, even taking out the trash)

Time Constraint _____ (The ship can take more time)

Personal Experience _____ (You have seen this stuff a million times)

How confident were you in your ability to compute a solution given the AOU data?

|______________|______________|______________|______________|

Not Confident	**Mildly Confident**	**Confident**	**Very Confident**	**Extremely Confident**

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Scenario 3

In this scenario you are required to destroy an enemy submarine. The submarine you are hunting is inferior to your own, you have multiple torpedoes, and your sensors are much better than their sensors. The CO wants to ensure that we sink the submarine on the first shot. Stop the scenario once you are comfortable with the COI solution to fire a torpedo.

What was your final solution for the COI?

Range + or - , Bearing + or - , Course + or -

Using a range between 1 and 10 (10 being the most), answer how much each factor weighed in your decision making.

Safety of ship _____ (Do not want to be shot at)

Job Satisfaction _____ (You have trained hard so show it)

Job Security/ Promotion _____ (Do not want to be relieved or demoted for collision)

Letting down the team _____ (Everyone is counting on you to make a good decision)

Mission Accomplishment _____ (Be the best boat on the waterfront)

Personal Satisfaction _____ (You do everything well, even taking out the trash)

Time Constraint _____ (The ship can take more time)

Personal Experience _____ (You have seen this stuff a million times)

How confident were you in your ability to compute a solution given the AOU data?

|______________|______________|______________|______________|

Not Confident	Mildly Confident	Confident	Very Confident	Extremely Confident

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Scenario 4

In this scenario you are required to destroy an enemy submarine. The submarine you are hunting is equivalent to your own. There is only one torpedo left and your sensors are similar to their sensors. The CO wants to ensure that we sink the submarine on the first shot and also to not get shot at ourselves. Stop the scenario once you are comfortable with the COI solution to fire a torpedo.

What was your final solution for the COI?

Range + or - , Bearing + or - , Course + or -

Using a range between 1 and 10 (10 being the most), answer how much each factor weighed in your decision making.

Safety of ship _____ (Do not want to sink the ship)

Job Satisfaction _____ (You have trained hard so show it)

Job Security/ Promotion _____ (Do not want to be relieved or demoted for collision)

Letting down the team _____ (Everyone is counting on you to make a good decision)

Mission Accomplishment _____ (Be the best boat on the waterfront)

Personal Satisfaction _____ (You do everything well, even taking out the trash)

Time Constraint _____ (The ship needs to make a decision quick)

Personal Experience _____ (You have seen this stuff a million times)

How confident were you in your ability to compute a solution given the AOU data?

|______________|______________|______________|______________|

Not Confident	Mildly Confident	Confident	Very Confident	Extremely Confident

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APPENDIX C: NASA TASK LOAD INDEX

We are interested not only in assessing your performance but also the experiences you had during the task. In the most general sense we are examining the “workload” you experienced. The factors that influence your experience of workload may come from the task itself, your feelings about your performance, how much effort you put in, or the stress and frustration you felt.

Since workload is something experienced by each person, there are no effective “rulers” that can be used to estimate the workload of different activities. One way to find out about workload is to ask people to describe the feelings they experienced. Because workload may be caused by many different factors, we would like you to evaluate several of them individually rather than lumping them into a single global evaluation of workload. Please read the definitions of the six scales carefully.

- Mental Demand: whether this task affects a user’s attention, brain, and focus.
- Physical Demand: whether this task affects a user’s health, makes a user tired, etc.
- Temporal Demand: whether this task takes a lot of time that a user can’t afford.
- Effort: whether a user has spent a lot of effort for this task.
- Performance: whether this task is heavy or light in terms of workload.
- Frustration: whether this task makes a user unhappy or frustrated.

Now you will perform a rating task. In the rating task, you will evalutate the task by marking each of the 6 rating scales at the point which matches your experience. Each scale has two end point descriptors that describe the scale. Please consider your responses carefully in distinguishing amoung the task conditions. Consider each scale individually.

MENTAL DEMAND

Low **High**

PHYSICAL DEMAND

Low **High**

TEMPORAL DEMAND

Low **High**

EFFORT

Low **High**

PERFORMANCE

Low **High**

FRUSTRATION

Low **High**

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APPENDIX D: POST SCENARIO QUESTIONNAIRE

Post Scenario Questionnaire. Subject #_____

Please consider your answers carefully and mark your responses on the scales provided. Any comments you have will be useful in developing tools and displays to be used on future submarine platforms. Thank you for your time and effort, your participation is very much appreciated.

1. **Having a graphical representation of the COI range estimation made it easier to compute a solution range.**

|_______________|_______________|_______________|_______________|

Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree

Please explain your rating;

____

____

____

____

2. **How useful were the AOUs in helping you compute solutions for the COI?**

|_______________|_______________|_______________|_______________|

Not Useful	Somewhat Useful	Moderately Useful	Very Useful	Extremely Useful

Please explain your rating;

____

____

____

____

3. **Did you find that there was a difference in using the AOU with regard to the two different tasks** (Navigation and Targeting)**?**

____

____

____

____

4. **Compared with past TMA experiences, the displayed AOU reduced the time required to compute the solution.**

Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree

Please explain your rating;

5. **What factors, in your mind, contribute to making these tasks difficult?** (Please list all factors and how each one made the different tasks hard to perform.)

1.
2.
3.
4.
5.

6. **During the targeting scenario, with regard to your contact solution, I considered the torpedoes abilities to detect a threat even though the solution may have been inaccurate.**

Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree

Please explain your rating;

7. **During the navigation scenarios what was your limiting factors that determined when you would go to PD?** (Range, contact course, time, other)

8. **It was easy to understand the meaning of the information presented in the displayed AOU.**

|______|______|______|______|

Strongly Disagree | Disagree | Neither Agree nor Disagree | Agree | Strongly Agree

Please explain your rating;

9. **I am highly confident in my abilities to conduct TMA in both targeting and navigation scenarios in the fleet.**

|______|______|______|______|

Strongly Disagree | Disagree | Neither Agree nor Disagree | Agree | Strongly Agree

Please explain your rating;

10. **How much did your prior training experience help you in decision making today?**

|______|______|______|______|

Very Little | Somewhat | Moderately | A lot | Great Extent

Please explain your rating;

11. **My experience with US torpedoes affected my decision making ability regarding contact solutions before firing.**

|______|______|______|______|

Strongly Disagree | Disagree | Neither Agree nor Disagree | Agree | Strongly Agree

Please explain your rating;

12. **Please give us any additional feedback you feel would be valuable.**

APPENDIX E: EXPERIMENTAL PROTOCOL

Experimental Protocol: Script in green was spoken aloud to each participant.

Prior to subject entering: Arrange consent forms, questionnaire ready, computer on, camera ready, program ready.	
"This is an unclassified experiment based on the problem of predicting uncertainty. We will be using four scenarios chosen in a random order. Two of the scenarios will be tactical and two will be navigational in nature and they will all be different with the exception of the mission requirements. I will explain the direction for each scenario before we start each one. The instructions that apply to one scenario may not apply to another."	
"After each scenario you will complete one page of the questionnaire as well as a workload questionnaire. After the last scenario you will be asked to complete the Post-scenario and bio questions."	
"The ellipses give you two areas of uncertainty. These are 66%, and 95% containment. They will be color coded differently for each scenario, but the percent containment will remain the same. - The solution screen will update itself approximately every 10sec. - Range Rings are established every 5000 yards. - Ownship data will be displayed on the right hand side of the screen for your convenience. - COI data is also available on the right hand side of the screen. You can consider this information to be the on watch FTOW's solution using the Fire Control computer. It is not truth but is available for your use. - Once you 'click' the stop button at the bottom of the screen the picture will disappear. At this point you will be required to fill out the appropriate forms. - There will be a video recorder observing your actions - Do you have any questions for me? If you have any questions during the scenario, please ask. "	Nav: This is a navigation scenario. The goal is to understand the situation well enough to come to PD. Hit "Stop" when you are ready to come to PD. Your submarine does not need to be on the best course to proceed to PD. Targeting: This is an approach and attack scenario. The goal is to localize the COI well enough to shoot. Hit "stop" when you know the solution. You do not need to be in a firing position.
"Your main focus will be range and bearing to the COI. The COI course is also requested but it is understood to be extremely difficult for an accurate course using the AOU. The order of importance in the scenarios will be range then bearing and a course if you feel comfortable with one. Let us begin"	Administer each scenario and record the results.
Remember to thank them for their time and to ask if they have any questions	

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APPENDIX F: CONSENT FORM

Naval Postgraduate School

Consent to Act as a Research Participant

How to Display Uncertainty in a Complex and Crowded Submarine Environment

You are being asked to participate in a research study. Before you give your consent to volunteer, it is important that you read the following information and ask as many questions as necessary to be sure you understand what you will be asked to do.

Investigator: James Prouty

Purpose of the Study: This study is designed to evaluate three different levels of expertise in submarine subject matter experts. Specifically these experts will be evaluated on their generated contact solutions based on their use of displays associated with target motion analysis.

Description of the Study: This study will explore and empirically evaluate new ways to graphically represent the Area of Uncertainty (AOU) for a submerged contact. I will administer scenarios to senior officers, junior officers, and fire control technicians who are submarine subject matter experts. By using the contact solutions generated by the participants, and a survey designed to collect their thought processes, I will investigate the different logistical strategies employed by the three groups.

Risks or Discomforts: Respondents range solutions will be published in a masters thesis distributed by the Naval Postgraduate School and analysis of the responses will be used to draw conclusions in the aforementioned thesis research paper. Anonymity is guaranteed to the participants in the experiment, and at no time will your name be published along with your answers. Only the thesis researchers will see the survey responses with respondent names included.

Benefits of the Study: Your participation in this study will aid in research regarding the effectiveness and possible changing of displays in the submarine environment.

Possible benefits of your participation in this study are an improved range display that may be generated as a result of this research.

Confidentiality: Names are only linked to data by anonymous codes. Only group, or otherwise anonymous, data will be reported. Confidentiality will be maintained to the extent allowed by law.

Incentives to Participate: Participation in this study is voluntary and you will not be paid to participate in this study.

Voluntary Nature of Participation: **Participation in this study is voluntary. Your choice of whether or not to participate will not influence your future relations with the Naval Postgraduate School. If you decide to participate, you are free to withdraw your consent and to stop your participation at any time without penalty or loss of benefits to which you are allowed.**

Questions about the Study: **If you have any questions about the research now, please ask. If you have questions later about the research, you may contact:**

James Prouty
(831) 392-5397
jrprouty@nps.edu

Prof. Susan Hutchins
(831) 656-3768
shutchins@nps.edu

If you have any questions about your rights as a participant in this study, you may contact the NPS-IRB Administrative Official:

Ms. Danielle Kuska
(831) 656-2099
dkuska@nps.edu

Consent to Participate: **The Naval Postgraduate School - Institutional Review Board has approved this consent form, as signified by the Board's stamp. The consent form must be reviewed annually and expires on the date indicated on the stamp.**

Your signature below indicates that you have read the information in this document and have had a chance to ask any questions you have about the study. Your signature also indicates that you agree to be in the study and have been told that you can change your mind and withdraw your consent to participate at any time. You have been given a copy of this consent form. You have been told that by signing this consent form you are not giving up any of your legal rights.

I FULLY UNDERSTAND THAT I AM MAKING A DECISION WHETHER OR NOT TO PARTICIPATE. MY SIGNATURE INDICATES THAT I HAVE DECIDED TO PARTICIPATE, HAVING READ THE INFORMATION PROVIDED ABOVE.

____
Name of Participant (please print)

______________________________________ ____________________
Signature of Participant Date

______________________________________ ____________________
Signature of Investigator Date
Subject # Date

APPENDIX G. RECORDED NASA TASK LOAD INDEX AND PERSONAL TRAITS FOR SCENARIO ONE

Sub #	Mental Demand	Physical Demand	Temporal Demand	Effort	Perform	Frustrate	Safety of Ship	Job Sat	Job Sec	Let Down	Mission Accom	Personal Satisfy	Time Constr	Personal Exper	Confid in Solution
Overall Mean	2.6	0.8	1.9	2.0	1.9	1.8	9.0	5.9	4.7	6.9	8.7	6.6	6.8	6.0	2.0

Sub #	Mental Demand	Physical Demand	Temporal Demand	Effort	Perform	Frustrate	Safety of Ship	Job Sat	Job Sec	Let Down	Mission Accom	Personal Satisfy	Time Constr	Personal Exper	Confid in Solution
3	2.8	0.4	0.6	1.6	1.3	2.6	10	5	5	10	10	7	8	9	1.5
4	3	0.2	0.4	0.8	0.4	1	10	10	7	10	10	9	4	8	1
7	1.9	0.1	2	3.1	1	2	10	10	5	10	10	8	8	1	1
8	2.7	0.6	1.6	2.2	1.5	1.3	10	5	4	10	10	5	7	8	2
9	3.2	0.1	2	3.2	1.6	1.2	10	10	10	10	8	8	6	8	1
10	2.7	1.7	2	2.3	1.5	2.1	9	7	5	6	10	4	8	4	3
11	3.4	2	2	1	2.6	1.4	1	10	1	10	7	7	8	7	2.5
12	3.8	2	0.4	3.6	2.6	1.8	10	7	7	9	10	6	10	5	1.8
14	3	1	2	1	1	1.6	10	8	6	10	10	9	9	9	2.4
15	2.1	0.1	0.6	0.5	0.9	1.3	10	7	9	8	10	7	8	6	1.4
Expert One															
Mean	2.9	0.8	1.4	1.9	1.4	1.6	9.0	7.9	5.9	9.3	9.5	7.0	7.6	6.5	1.8

Sub #	Mental Demand	Physical Demand	Temporal Demand	Effort	Perform	Frustrate	Safety of Ship	Job Sat	Job Sec	Let Down	Mission Accom	Personal Satisfy	Time Constr	Personal Exper	Confid in Solution
1	1.9	0.35	0.95	1.1	1.16	1.85	9	7	7	8	6	7	8	5	1
2	2.8	0.3	2	2.1	1.7	2.4	8	6	8	7	6	9	8	3	1
5	3.4	1.2	3.1	2.1	2.1	2.1	10	7	4	5	8	7	8	5	2
6	3.4	0.5	3.4	2.9	2.9	3.6	8	1	1	6	8	6	8	1	1
13	3.7	2.3	3.4	3.6	3.5	3.7	9	5	4	6	10	4	10	5	2
18	3	0.4	2	2.6	2	2.4	10	7	4	7	5	7	5	4	1.5
19	3.6	0.8	3.8	3.8	3	4	5	5	2	8	8	8	10	8	0
21	1.4	1.8	1.6	1.6	1.4	0.6	1	5	4	3	6	7	2	8	2
25	1	0.3	2.7	2.4	2	0.2	10	1	1	2	9	8	10	5	0.8
30	2.7	1.1	2.7	2.1	1.9	2.2	10	7	7	8	10	9	8	7	2.5
Expert Two															
Mean	2.7	0.9	2.6	2.4	2.2	2.3	8.0	5.1	4.2	6.0	7.6	7.2	7.7	5.1	1.4

Sub #	Mental Demand	Physical Demand	Temporal Demand	Effort	Perform	Frustrate	Safety of Ship	Job Sat	Job Sec	Let Down	Mission Accom	Personal Satisfy	Time Constr	Personal Exper	Confid in Solution
16	2	1	3	1	2	2	10	6	6	10	10	8	2	8	2.5
17	3.1	1.6	2.7	2.3	2.2	1.6	10	7	10	10	10	7	5	7	2.8
20	2.4	0.1	1	1	0.6	2.6	10	7	2	6	8	7	4	8	2.5
22	2.5	1.1	1	2.2	1.5	0.9	10	9	7	7	8	8	4	6	2.5
23	3	0.3	1.4	1.6	1.1	0.3	10	1	1	2	10	2	9	7	3
24	2.2	1.7	0.5	2.2	3.1	1.8	10	8	4	8	8	8	8	2	2
26	1.6	0.4	2.3	1.9	2.6	2.6	9	1	1	1	8	1	1	1	2
27	2.5	0.1	2.2	0.8	2.4	0.8	10	5	10	7	8	8	9	9	2.6
28	1.4	0.2	1.6	1	1.3	1.1	10	3	3	5	7	4	6	6	2
29	1.4	0	0.9	1.8	2	1	10	1	1	1	8	6	7	8	3
Expert Three															
Mean	2.2	0.7	1.7	1.6	1.9	1.5	9.9	5.0	4.5	5.7	8.5	5.9	5.5	6.2	2.5

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APPENDIX H. RECORDED NASA TASK LOAD INDEX AND PERSONAL TRAITS FOR SCENARIO TWO

Overall Mean	2.4	0.8	1.5	1.8	1.6	1.6	9.5	5.9	4.8	7.1	8.0	6.7	5.6	6.4	2.4
Sub #	Mental Demand	Physical Demand	Temporal Demand	Effort	Perform	Frustrate	Safety of Ship	Job Sat	Job Sec	Let Down	Mission Accom	Personal Satisfy	Time Constr	Personal Exper	Confid in Solution
3	3.2	0.3	0.8	1.6	1.4	2.6	10	6	4	10	10	5	7	6	2
4	2.6	0.3	0.4	0.8	0.3	0.4	10	10	6	10	10	9	4	8	2
7	1.6	0	1.2	2.9	1.2	1.1	10	9	4	9	10	9	2	4	1.8
8	3	0.4	0.4	2.4	1	1.6	10	5	5	10	10	3	2	8	3
9	3.4	0.4	1.4	2.8	1.8	1.6	10	8	8	10	8	9	10	8	2
10	3	2	3	2	1.2	2.4	10	7	4	9	6	4	8	3	3
11	3	1	2.6	1.6	1	1.2	7	7	1	10	8	7	6	5	2.5
12	3.6	2	0.4	3.6	2.4	1	10	8	8	10	10	7	8	6	2.1
14	3.2	0.8	1.6	0.8	0.8	1.8	10	9	6	10	10	9	10	9	2
15	2.2	0.4	0.7	0.6	1	1.4	10	8	9	8	10	7	1	6	1.5
Expert One															
Mean	2.9	0.8	1.3	1.9	1.2	1.5	9.7	7.7	5.5	9.6	9.2	6.9	5.8	6.3	2.2

Sub #	Mental Demand	Physical Demand	Temporal Demand	Effort	Perform	Frustrate	Safety of Ship	Job Sat	Job Sec	Let Down	Mission Accom	Personal Satisfy	Time Constr	Personal Exper	Confid in Solution
1	1.5	0.5	0.7	0.85	1	1.3	9	8	7	8	6	7	8	6	2.2
2	2.6	0.5	1.6	1.8	1.6	2	7	6	8	5	5	8	4	3	1
5	3.5	1	2.1	2	2	2	10	7	4	4	7	8	6	5	3
6	3.2	0.6	3.4	2.4	2.6	2.2	10	1	1	6	6	6	1	1	1
13	2.5	2	2.3	2.4	2.2	2.4	4	5	2	5	10	4	7	6	1.7
18	2	0.5	2.1	2.5	2.1	2.6	8	7	5	7	5	7	3	4	1
19	1.4	0.6	0.8	1	1	3	10	4	5	7	7	7	3	5	2
21	2.2	2.1	1.9	1.8	1.9	2	10	5	6	7	7	7	10	7	2.8
25	2	0.1	2.7	2	1.4	1	10	4	5	5	8	7	8	10	3.1
30	2.1	0.8	1.5	1.5	1.1	0.6	8	7	7	8	10	8	7	8	2.8
Expert Two															
Mean	2.3	0.9	1.9	1.8	1.7	1.9	8.6	5.4	5.0	6.2	7.1	6.9	5.7	5.5	2.1

Sub #	Mental Demand	Physical Demand	Temporal Demand	Effort	Perform	Frustrate	Safety of Ship	Job Sat	Job Sec	Let Down	Mission Accom	Personal Satisfy	Time Constr	Personal Exper	Confid in Solution
16	2	1	3	1	2	2	10	6	6	10	10	8	2	8	2.7
17	2.9	1.6	2.4	2.2	2.4	1.2	10	7	10	10	10	7	2	7	3
20	1.5	0.1	0.6	1.2	1.1	3	9	7	1	4	7	8	3	8	2.8
22	2.4	1.1	1.4	2	1.2	1	10	8	6	8	8	8	5	7	3
23	2.6	0.2	0.6	1.4	0.9	0.1	10	1	1	3	8	2	7	6	3
24	2	1.4	0.4	2	3	2	10	8	4	8	8	8	8	4	2
26	1.2	0.7	2	1.4	2	3	10	1	1	1	1	1	8	8	3
27	2.3	0.3	0.4	0.5	1.8	0.5	10	5	10	7	8	8	9	9	2.8
28	1	0.4	1.6	1.4	1.3	1.1	10	3	3	5	7	5	5	5	2
29	1.4	0	0.9	1.8	2	1	10	1	1	1	8	7	7	7	2
Expert Three															
Mean	1.9	0.7	1.3	1.5	1.8	1.5	9.9	5.0	4.3	5.7	7.5	6.2	5.6	6.9	2.6

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APPENDIX I. RECORDED NASA TASK LOAD INDEX AND PERSONAL TRAITS FOR SCENARIO THREE

Sub #	Mental Demand	Physical Demand	Temporal Demand	Effort	Perform	Frustrate	Safety of Ship	Job Sat	Job Sec	Let Down	Mission Accom	Personal Satisfy	Time Constr	Personal Exper	Confid in Solution
Overall Mean	2.7	1.0	1.6	2.2	2.1	1.8	8.3	5.9	3.8	7.3	8.7	6.9	5.7	5.4	1.9
3	2.6	0.3	0.5	0.8	1	0.8	10	7	4	10	10	7	9	5	2
4	2.6	0.3	0.5	1	0.5	1.6	5	10	7	10	10	9	3	8	0.5
7	2.9	0.1	1.6	3.2	1.4	1.4	10	9	3	10	10	9	4	5	1.8
8	3	0.4	0.4	2	2	2	10	5	2	10	10	5	2	5	1
9	3.5	0.6	1.5	2.9	2.2	1.2	10	8	8	10	10	10	6	5	1
10	3.2	1.5	1.6	2	1.8	2.8	8	7	3	6	9	5	10	2	2
11	4	3	0.4	2.6	3	1.6	1	7	1	10	10	7	1	8	3.5
12	3.6	3	1	3.2	3	1	10	8	8	10	10	9	5	6	2.2
14	2.9	0.7	1.3	0.8	0.8	1.8	10	9	7	10	10	9	9	9	2.7
15	1.4	0.3	0.9	0.7	1.1	1.8	10	7	4	9	10	7	6	6	1.2
Expert One															
Mean	3.0	1.0	1.0	1.9	1.7	1.6	8.4	7.7	4.7	9.5	9.9	7.7	5.5	5.9	1.8
Sub #	Mental Demand	Physical Demand	Temporal Demand	Effort	Perform	Frustrate	Safety of Ship	Job Sat	Job Sec	Let Down	Mission Accom	Personal Satisfy	Time Constr	Personal Exper	Confid in Solution
1	3	0.8	1.15	1.3	1.2	2.3	9	8	7	8	7	8	9	6	2.6
2	2.1	0.2	1.2	2	1.6	1.8	6	7	5	8	7	9	6	3	2
5	3.4	2.9	2	2.9	2.9	2.4	10	8	3	4	7	7	8	1	2
6	3.2	0.7	2	2.3	2.4	2.1	8	1	1	7	8	5	5	1	1.2
13	3	2	1.8	3	2.5	2.1	1	1	1	3	6	6	10	2	1
18	2.8	0.5	1.6	2.6	2.4	2	5	7	4	7	8	7	4	3	2
19	3.6	0.8	3.8	3.8	3	4	5	5	2	8	8	8	10	8	0
21	1.8	1.9	1.8	1.8	1.8	1.9	10	6	4	7	5	6	10	6	1.5
25	1.8	0.2	2.6	2.4	1.4	0.2	10	3	2	8	9	8	4	5	1.3
30	2.9	1.6	1.8	2.9	2.2	1.9	10	8	8	9	10	8	6	6	1.8
Expert Two															
Mean	2.8	1.2	2.0	2.5	2.1	2.1	7.4	5.4	3.7	6.9	7.5	7.2	7.2	4.1	1.5
Sub #	Mental Demand	Physical Demand	Temporal Demand	Effort	Perform	Frustrate	Safety of Ship	Job Sat	Job Sec	Let Down	Mission Accom	Personal Satisfy	Time Constr	Personal Exper	Confid in Solution
16	2	1	3	1	2	2	10	6	6	10	10	8	2	8	3
17	3.6	1.6	3	2.6	2.3	1.4	10	7	10	10	7	7	3	7	3.8
20	1.5	0.1	1.2	1.3	1	2.8	8	7	1	4	7	7	6	8	2.5
22	2.7	1.5	2	3.2	2.8	3.5	9	9	5	7	9	9	7	6	1.3
23	3.2	0.4	1.2	1.8	1.2	0.4	10	1	1	2	10	2	4	4	3.2
24	2.1	1.8	0.7	2.3	3.2	1.6	10	8	4	8	8	8	6	4	1.8
26	1.6	0.4	2.3	1.9	2.6	2.6	9	1	1	1	8	1	1	1	2
27	3	0.1	1	1	2.6	1.1	10	5	3	9	9	7	7	10	3.3
28	2	0.7	2	1.6	1.6	1.6	5	4	3	6	9	4	8	5	2
29	1	0	0.9	1.5	2	1	10	1	1	1	7	7	7	8	2
Expert Three															
Mean	2.3	0.8	1.7	1.8	2.1	1.8	9.1	5.0	3.5	5.8	8.4	6	5.1	6.1	2.5

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APPENDIX J. RECORDED NASA TASK LOAD INDEX AND PERSONAL TRAITS FOR SCENARIO FOUR

Sub #	Mental Demand	Physical Demand	Temporal Demand	Effort	Perform	Frustrate	Safety of Ship	Job Sat	Job Sec	Let Down	Mission Accom	Personal Satisfy	Time Constr	Personal Exper	Confid in Solution
Overall Mean	2.7	1.0	2.0	2.2	2.1	2.0	8.7	6.3	3.7	7.6	9.0	7.2	7.6	5.7	2.1
3	3	0.2	0.2	0.9	1.1	2	3	6	5	9	9	9	9	9	0
4	2.8	0.4	0.7	1.1	0.7	0.6	10	10	6	10	10	9	10	10	2
7	2.9	0.1	3.4	3	1.9	2.2	10	9	2	10	10	9	8	5	1.6
8	2.4	0.2	2.2	2.7	2	1	10	5	3	10	10	3	10	8	2
9	3.6	0.2	3	3	2	2.4	10	10	8	10	10	10	4	7	3
10	3.4	2.4	3.5	3	2.1	3.4	9	6	4	8	7	5	10	3	2
11	4	3	0.8	3	3	1.6	1	10	1	10	10	10	7	7	3
12	3.7	3	1	3.2	3.2	1.3	10	8	6	9	10	8	9	5	2
14	3.1	0.6	1.5	0.7	0.9	2	10	9	7	10	10	9	10	9	2.7
15	2.6	0.2	0.8	0.8	1.2	2	10	8	4	9	10	7	10	6	2.3
Expert One															
Mean	3.2	1.0	1.7	2.1	1.8	1.9	8.3	8.1	4.6	9.5	9.6	7.9	8.7	6.9	2.1
Sub #	Mental Demand	Physical Demand	Temporal Demand	Effort	Perform	Frustrate	Safety of Ship	Job Sat	Job Sec	Let Down	Mission Accom	Personal Satisfy	Time Constr	Personal Exper	Confid in Solution
1	2.7	1.2	1.5	1.5	1.4	2.5	10	8	8	9	9	8	7	6	2.9
2	2.4	0.4	1.4	2	1.6	2.2	8	7	3	8	8	10	7	3	1
5	3.6	2	3	3	3	2.5	10	6	4	5	7	8	4	1	2
6	3.2	0.7	1.8	2.3	2.5	1.6	9	1	1	6	9	5	9	1	1
13	3.4	1.6	2.5	3.2	3	3	3	3	1	6	10	7	10	5	1
18	3	0.6	2.6	3	2.6	2.8	8	7	4	7	7	7	7	4	2
19	1.9	0.3	1.3	1.3	1.3	3.6	5	6	2	9	10	8	8	8	1
21	1.8	1.9	1.7	1.6	2	1.8	10	7	4	6	8	7	10	6	2
25	1	1.4	4	2.8	2.6	1.6	10	5	4	7	8	8	7	5	2.5
30	3	1.6	1.8	2.9	2.3	1.9	8	8	5	8	10	7	8	4	1.7
Expert Two															
Mean	2.6	1.2	2.2	2.4	2.2	2.4	8.1	5.8	3.6	7.1	8.6	7.5	7.7	4.3	1.7
Sub #	Mental Demand	Physical Demand	Temporal Demand	Effort	Perform	Frustrate	Safety of Ship	Job Sat	Job Sec	Let Down	Mission Accom	Personal Satisfy	Time Constr	Personal Exper	Confid in Solution
16	2	1	3	1	2	2	10	6	6	10	10	8	2	8	3
17	3.8	1.6	3.1	2.7	2.4	1.8	10	7	10	10	10	7	7	7	3
20	1.6	0.1	1.4	1.4	1.2	3.4	8	6	1	6	8	7	7	8	2.5
22	3	1.2	1.8	3	2.8	2.4	10	8	4	8	9	9	6	3	2
23	3.4	0.4	0.8	2	1.2	0.2	3	5	1	3	10	6	8	6	2
24	2.2	1.8	0.7	2.4	3.3	2.1	10	8	4	8	8	8	7	5	1.9
26	2	0.2	2.6	2.4	2.3	3	10	2	2	3	8	3	8	1	1
27	3.5	0.2	1.6	1.6	3.2	1.5	10	5	3	9	9	7	7	10	2.7
28	2	0.8	2	0.7	1.6	1.6	10	4	3	7	8	4	5	4	2
29	1	0	0.6	1	1.5	1	10	1	1	1	7	7	8	8	3
Expert Three															
Mean	2.5	0.7	1.8	1.8	2.2	1.9	9.1	5.0	3.5	6.5	8.7	6.6	6.5	6	2.3

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APPENDIX K. SCENARIO ONE RAW DATA

Expert	Time	Range	Range +/-	Range Difference	Within Range	Over or Under
1	14.500	3.0	1.5	3.041	0	0
1	11.500	4.0	1.0	2.892	0	0
1	5.167	3.3	0.8	0.521	1	1
1	7.167	3.5	1.0	0.771	1	0
1	7.000	3.5	0.5	0.641	0	0
1	11.167	2.0	1.5	**5.381***	0	0
1	12.667	3.5	1.0	3.083	0	0
1	6.167	6.0	1.0	2.623	0	1
1	6.000	4.0	0.5	0.746	0	1
1	14.833	4.7	1.5	1.262	1	0
2	7.000	4.0	1.0	0.011	1	0
2	9.667	2.0	0.5	4.284	0	0
2	8.000	4.0	1.0	0.932	1	0
2	14.833	5.0	0.5	0.962	0	0
2	14.833	4.5	1.0	1.462	0	0
2	15.000	5.0	2.0	0.962	1	0
2	5.000	4.0	0.2	1.335	0	1
2	6.167	3.0	1.0	0.377	1	0
2	5.667	4.2	1.3	1.068	1	1
2	4.500	3.2	1.0	0.777	1	1
3	7.500	2.5	1.0	2.034	0	0
3	6.300	2.5	1.5	1.002	1	0
3	4.667	4.5	0.5	2.053	0	1
3	7.667	3.5	1.2	1.166	1	0
3	9.000	3.8	0.5	1.939	0	0
3	8.000	6.0	1.5	1.068	1	1
3	5.167	3.8	0.4	1.021	0	1
3	5.000	2.5	0.2	0.165	1	0
3	7.300	4.5	1.0	0.098	1	1
3	10.000	4.0	1.0	2.557	0	0

* Note: This value is greater than three standard deviations from the mean.

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APPENDIX L. SCENARIO TWO RAW DATA

Expert	Time	Range	Range +/-	Range Difference	Within Range	Over or Under
1	8.000	12.0	3.0	4.012	0	0
1	2.667	10.0	3.0	4.967	0	0
1	2.500	10.0	2.0	4.804	0	0
1	7.000	11.0	3.0	4.560	0	0
1	6.167	12.0	2.0	3.237	0	0
1	5.667	7.0	2.0	8.275	0	0
1	8.500	12.0	2.0	4.259	0	0
1	5.667	10.0	1.0	5.275	0	0
1	1.833	7.5	1.0	6.555	0	0
1	7.833	14.0	2.0	1.918	1	0
2	4.000	7.5	2.0	8.017	0	0
2	10.300	15.0	3.0	2.650	1	0
2	6.667	15.0	5.0	0.390	1	0
2	3.500	8.0	0.5	7.472	0	0
2	4.667	12.0	2.0	3.413	0	0
2	11.833	16.0	2.0	3.382	0	0
2	2.833	10.0	1.0	5.061	0	0
2	8.000	12.0	2.0	4.012	0	0
2	5.833	15.5	4.0	0.225	1	1
2	2.833	10.0	2.0	5.061	0	0
3	2.667	12.0	4.0	2.967	1	0
3	6.500	14.0	1.0	1.267	0	0
3	6.167	11.0	3.0	4.237	0	0
3	4.000	9.0	2.6	6.517	0	0
3	9.000	13.0	3.0	3.573	0	0
3	4.300	8.5	0.3	6.977	0	0
3	2.500	9.0	2.0	5.804	0	0
3	2.667	12.0	2.0	2.967	0	0
3	5.667	10.0	2.0	5.275	0	0
3	2.667	11.0	5.0	3.967	1	0

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APPENDIX M. SCENARIO THREE RAW DATA

Expert	Time	Range	Range +/-	Range Difference	Within Range	Over or Under
1	5.167	4.0	0.5	1.221	0	1
1	10.000	3.4	2.0	3.157	0	0
1	9.500	4.0	1.5	2.147	0	0
1	15.000	4.5	1.0	1.424	0	0
1	5.833	3.5	0.5	0.368	1	1
1	7.300	3.0	0.5	1.402	0	0
1	12.667	4.0	1.0	2.583	0	0
1	14.667	5.0	1.0	1.041	0	0
1	7.667	3.0	0.5	1.666	0	0
1	7.500	3.0	0.5	1.534	0	0
2	6.300	2.5	1.0	1.002	0	0
2	6.000	3.0	1.0	0.254	1	0
2	13.000	4.5	1.0	1.985	0	0
2	10.833	4.0	0.5	3.106	0	0
2	15.000	5.5	1.0	0.424	1	0
2	15.000	2.0	**3.0***	3.962	0	0
2	6.667	3.0	1.0	0.882	1	0
2	5.833	3.5	0.5	0.368	1	1
2	5.167	4.0	0.5	1.221	0	1
2	6.300	4.0	1.0	0.498	1	1
3	7.667	3.6	1.6	1.066	1	0
3	9.000	3.5	0.5	2.239	0	0
3	9.500	4.0	1.0	2.147	0	0
3	11.167	4.0	1.0	3.381	0	0
3	5.167	4.5	0.5	1.721	0	1
3	6.833	3.0	1.5	1.011	1	0
3	4.833	4.0	1.0	1.445	0	1
3	15.000	6.0	2.0	0.038	1	1
3	6.300	2.3	0.3	1.202	0	0
3	6.667	2.1	0.3	1.782	0	0

* Note: This value is greater than three standard deviations from the mean.

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APPENDIX N. SCENARIO FOUR RAW DATA

Expert	Time	Range	Range +/-	Range Difference	Within Range	Over or Under
1	5.167	4.0	0.5	1.221	0	1
1	10.000	3.4	2.0	3.157	0	0
1	9.500	4.0	1.5	2.147	0	0
1	15.000	4.5	1.0	1.424	0	0
1	5.833	3.5	0.5	0.368	1	1
1	7.300	3.0	0.5	1.402	0	0
1	12.667	4.0	1.0	2.583	0	0
1	14.667	5.0	1.0	1.041	0	0
1	7.667	3.0	0.5	1.666	0	0
1	7.500	3.0	0.5	1.534	0	0
2	6.300	2.5	1.0	1.002	0	0
2	6.000	3.0	1.0	0.254	1	0
2	13.000	4.5	1.0	1.985	0	0
2	10.833	4.0	0.5	3.106	0	0
2	15.000	5.5	1.0	0.424	1	0
2	15.000	2.0	3.0	3.962	0	0
2	6.667	3.0	1.0	0.882	1	0
2	5.833	3.5	0.5	0.368	1	1
2	5.167	4.0	0.5	1.221	0	1
2	6.300	4.0	1.0	0.498	1	1
3	7.667	3.6	1.6	1.066	1	0
3	9.000	3.5	0.5	2.239	0	0
3	9.500	4.0	1.0	2.147	0	0
3	11.167	4.0	1.0	3.381	0	0
3	5.167	4.5	0.5	1.721	0	1
3	6.833	3.0	1.5	1.011	1	0
3	4.833	4.0	1.0	1.445	0	1
3	15.000	6.0	2.0	0.038	1	1
3	6.300	2.3	0.3	1.202	0	0
3	6.667	2.1	0.3	1.782	0	0

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LIST OF REFERENCES

Andre, A.D., and Cutler, H.A. (1998). Displaying Uncertainty in Advanced Navigation Systems. *In Proceedings of the Human Factors and Ergonomics Society 42nd Annual Meeting*, October 5-9, in Chicago, Illinois.

Bandura, A. (1997). Self-efficacy: The exercise of control. New York: W.H. Freeman.

Bakos, G, K. (1995). Submarine Approach and Attack Tactics-Simulation and Analysis, Master's Thesis, Naval Postgraduate School, Monterey California.

Bennett, K.B., Toms, M.L., and Woods, D.D. (1993). Emergent Features and Graphical Elements: Designing More Effective Configural Displays, The Human Factors and Ergonomics Society, Inc, 35(1): 71-97.

Bisantz, A.M., Finger, R., Seong, Y., and Llinas, J. (1999). Human Performance and Data Fusion Based Decision Aids, *International Conference on Information Fusion (Fusion '99)*, July 6-8, in Sunnyvale, California.

Bradley, A., Zhang, X., and Thibos, L. (1989). Achromatizing The Human Eye, Annual Meeting of the American Academy of Optometry, December 7-11, New Orleans, Louisiana.

Brolese, A. (2005). Graphical Representations of Uncertainty Within Sub-surface Environments. Paper presented at the *XXVII Annual Conference of the Cognitive Science Society*, July 25-26, Stresa, Italy.

Brolese, A. and Huf, S. (2006). Visualizing uncertainty to improve operators' spatial proximity judgments in uncertain surroundings, *The Human Factors and Ergonomics Society 50th Annual Meeting*, October 16-20, in San Francisco, CA.

Carlisle, J. (2006). Poker Counselor's Corner, Pokernews.com (43), http://www.pokernews.com/news/2006/2/poker-counselor-corner-43.htm, accessed on February 03, 2006.

Coll, P, F. (1994). Target Motion Analysis from a Diesel Submarine Perspective, Master's Thesis, Naval Postgraduate School, Monterey, California.

Cunningham, A., and Thomes, B. (2005). Target Motion Analysis Visualisation, *Presented at the Asia-Pacific Symposium on Information Visualisation*, January 27-29, Sydney, Australia.

De Groot, A.D. (1965). Thought and choice in chess. The Hague: Mouton.

Dry, M., Lee, M., Vickers, D., and Huf, S. (2005). Psychological Implications for Submarine Display Design, DSTO Defense Science and Technology Organisation, Technical Report DSTO-TR-1766, Edinburgh, Australia.

Ettenson, R., Shanteau, J., and Krogstad, J. (1987). Expert Judgment: Is More Information Better?, Psychological Reports, 60(1): 227-238.

Edwards, W. (1992). Discussion: Of Human Skills, Organizational Behavior and Human Decision Processes, 53(1): 267-277.

Hart, S., and Staveland, L. (1988), Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research, in P. Hancock and N. Meshkati (eds.), *Human Mental Workload*, North-Holland: 139–183.

Hutchins, S.G. (1996). Principles for Intelligent Decision Aiding, Naval Command, Control, and Ocean Surveillance Center, RDT&E Division, Technical Report 1718. San Diego, California.

Jones, L., Lane, A.M., and Stevens, M.J. (2002). Coping with Failure: The Effects of Self-Esteem and Coping on Changes in Self-Efficacy, *Journal of Sport Behavior,* 25(4), 331-345.

Kirschenbaum, S.S., and Arruda, J.E. (1994). Effects of graphic and verbal probability information on command decision making. Human Factors, 36 (3), 406-418

Kahneman, D., Slovic, P., and Tversky, A. (Eds.) (1982). *Judgment under uncertainty: heuristics and biases*. New York: Cambridge Univ. Press.

Larkin, J.H., and Simon, H.A. (1987). Why a diagram is (sometimes) worth 10,000 words. Cognitive Science, 11(1): 65-99.

Lerch, F.J., and Prietula, M.J. (1989). How do we trust machine advice? In Salvendy, G. and Smith, M.J. (Eds.), *Designing and using human-computer interface and knowledge based systems* (410-419). Elsevier Science Publishers, North-Holland.

Liberty, S.L. (2006). Active vs. Passive SONAR: When Does it Make Sense to go Active?, Master's Thesis, Naval Postgraduate School, Monterey California.

Narayanan, H., Introduction to Diagrammatic Reasoning, EduTech Institute & College of Computing, Georgia Institute of Technology, Febuary, 22, 1997, http://zeus.cs.hartford.edu/~anderson/intro.html, accessed on February 24, 2007.

L-3 Communications SeaBeam Instruments,L3 Theory Operation, Chapter 2, http://www.ldeo.columbia.edu/res/pi, accessed on January 10, 2006.

Omodei, M., Wearing, A., McLennan, J., Elliott, G., and Clancy, J. (2003). More is better? Problems of self-regulation in naturalistic decision making situations. In *How professionals make decisions*. Montgomery, H., Lipshitz, R. and Brehmer, B. (eds). Elsevier.

Parfitt, G., and Pates, J. (1999). The effects of cognitive and somantic anxiety and self-confidence on components of performance during competition, *Journal of Sports Sciences,* 17(5), 351-356.

Peebles, D., and Cheng, P.C.H. (2003). Modeling the Effect of Task and Graphical Representation on Response Latency in a Graph Reading Task, Human Factors, 45(1), 28-46.

Potter, S.S., Elm, W.C., Roth, E.M., and Woods, D.D. (2001). The Development of a Computer-Aided Cognitive System Engineering Tool to Facilitate the Design of Advanced Decision Support Systems. Final Rept. Apr 1998-Apr 2000, Technical Report AFRL-HE-WP-TR-2001-0125, United States Air Force Research Laboratory.

Roth, E. M., and Woods, D. D. (1988). Aiding Human Performance: I. Cognitive Analysis, Le Travail Humain 51(1), 39-64.

Roth, E. M., Patterson, E. S., and Mumaw, R. J. (2002). Cognitive Engineering: Issues in User-Centered System Design. In J. J. Marciniak (Ed.), *Encyclopedia of Software Engineering, 2nd Edition* (163-179). New York: Wiley-Interscience, John Wiley & Sons.

Schmidt, V., Chayes, D., and Caress, D., The MB-System Cookbook. MB-System 5.0.8, February, 2006, http://www.ldeo.columbia.edu/res/pi/MB-System/mb-cookbook/index.html, accessed on January 11, 2007.

Schunn, C. D., Kirschenbaum, S. S., and Trafton, J. G. In Press. The ecology of uncertainty: Sources, indicators, and strategies for informational uncertainty, International Journal of Human-Computer Studies.

Serfaty, D., MacMillan, J., Entin, E. E., and Entin, E. B. (1997). *The Decision-Making Expertise of Battle Commanders*, In CE Zsambok & G Klein (Eds.), *Naturalistic Decision Making* (233-246). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Shanteau, J. (1987). Psychological characteristics of expert decision makers, In: J. Mumpower, O. Renn, L.D. Phillips and V.R.R. Uppuluri (Eds), *Expert judgement and expert systems*. Berlin: Springer-Verlag.

Shanteau, J. (1988). Psychological Characteristics and Strategies of Expert Decision Makers, Acta Psychologica, 68(1): 203-215.

Shanteau, J. (1989). Psychological characteristics and strategies of expert decision makers. In B. Rohrmann, L.R. Beach, C. Vlek, & S.R. Watson (Eds.), *Advances in decision research*, 203-215. Amsterdam: North Holland.

Shanteau, J. (1991). Psychological characteristics and strategies of experts. In G. Wright & F. Bolger (Eds.), *Expertise and decision support*. New York: Plenum.

Shanteau, J. (1992a). Competence in Experts: The Role of Task Characteristics*, Organizational Behavior and Human Decision Processess*, 53(1): 252-266.

Shanteau, J. (1992b). How Much Information Does An Expert Use? Is It Relevant?, *Acta Psychologica*, 81(1): 75-86.

Shanteau, J., and Stewart, T.R. (1992). Why Study Expert Decision Making? Some Historical Perspectives and Comments, Organizational behavior and human decision processes, 53: 95-106.

Sheridan, T.B. (1988). Trustworthiness of command and control systems. In IFAC Man-Machine Systems, 427-431, Oulu, Finland.

Sitko, M. L. University of Cincinnati, “CollegePhysicsIII.”, Apache/2.0.54 (Fedora) Server at www.physics.uc.edu Port 80, 2002, Department of Physics 400 Geology/Physics Building P.O. Box 210011 Cincinnati, OH 45221-0011, April 30, 2004. http://www.physics.uc.edu/~sitko/CollegePhysicsIII/14-Sound/Sound.pdf, accessed on January 11, 2007.

Slovic, P., Fischhoff, B., and Lichtenstein, S. (1985). Regulation of risk: A psychological perspective. In R. Noll (Ed.), *Social science and regulatory policy*. Berkeley: University of California Press.

Tufte, E.R. (2001). The Visual Display of Quantitative Information. 2nd Edition, Graphics Press, Cheshire, Connecticut.

Webster’s 1993. Merriam Webster’s Collegiate Dictionary. Springfield, MA: Merriam- Webster, Inc.

Wickens, C. D., Lee, J., and Liu, Y. (2004). *An Introduction to Human Factors Engineering,* Saddle River, N.J., Pearson Education, Inc.

Woodman, T., and Hardy, L. (2003). The relative impact of cognitive anxiety and self-confidence upon sport performance: A meta-analysis, *Journal of Sports Sciences*, 21(6), 443-457.

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